AD-A202 743

TECHNICAL REPORT BRL-TR-2943

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EFFECTS OF INTERFACE CONFIGURATIONS ON PRESSURE WAVES IN GUNS

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NOVEMBER 1988

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) BRL-TR-2943	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Ballistic Research Laboratory 6b. OFFICE SYMBOL (If applicable) SLCBR-IB-A	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Aberdeen Proving Ground Maryland 21005-5066	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62618A	1L162618AH	8000	

11. TITLE (Include Security Classification)

Effects of Interface Configurations on Pressure waves in Guns

12. PERSONAL AUTHOR(S)

Carl R. Ruth, James W. Evans, James E. Bowen and John R. Hewitt

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical Report	FROM Jan 83 TO Jan 85		

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
19	01	
21	02	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Interior Ballistics, Pressure Waves, Projectile Geometry, Guns

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

— Improper ignition of a gun or howitzer propelling charge can lead to potentially damaging pressure waves, threatening both integrity of the weapon system and safety of the operating crew. High levels of pressure waves are often accompanied by ballistic variability, increases in chamber pressure and, on occasion, can lead to breechblows, fuze malfunctions, projectile prematures, and fin damage. While weapons firing low performance charges can usually sustain a fairly high level of pressure waves with no adverse effects, the higher pressure environment associated with most high performance charges appears to aggravate the situation, with moderate levels of pressure waves sometimes escalating into major problems.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☒ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Carl R. Ruth	22b. TELEPHONE (Include Area Code) (301)278-6192 22c. OFFICE SYMBOL SLCBR-IB-A

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

The new generation of tank ammunition is characterized by high operating pressures and hence could be particularly susceptible to pressure wave problems. With the protrusion of the projectile base well into the chamber (or cartridge case), configurally complex regions adjacent to the projectile boattail can be occupied by either propellant or ullage. Pressure readings at or near these locations may be significantly influenced by localized combustion, grain damage, or pressure wave focusing (associated with a change in cross-sectional area), resulting in inconsistent or misleading data, particularly as manifested in the pressure difference measurement. Since these data are used to assess pressure wave safety, an issue of great concern for high performance tank ammunition, accurate pressure measurements are essential.

In this study, test projectiles were fabricated with both conical and cylindrical bases. Firings were conducted in a highly instrumented 105-mm, M68 tank gun, and detailed analysis of pressure-time and pressure difference-time data was conducted to assess the influence of base configuration on the formation of pressure waves and their measurement. Representative data are presented and discussed in detail. Keywords; [illegible] projectile geometry; [illegible]

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Messrs. J. Frankle, A. Horst and J. Rocchio for their technical assistance and suggestions pertinent to the basic problem presented in this report. Gratitude is also expressed to Mr. J. Stabile from the Sandy Point Firing facility for monitoring the instrumentation and recording the data for the test firings.

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I. INTRODUCTION

In the past few years, much attention has been given to the effects of longitudinal gas pressure waves in guns and howitzers on the safe and efficient operation of the weapon. Much of the attention has gone to howitzer systems firing high-zone charges such as the M203A1 which incorporates both a variety of parasitic components and a low-pressure igniter into its fabrication. Recent experience has shown that small changes within the charge or between the charge/chamber interface can produce large changes in charge stability.[1-4] Studies have shown the causal connection between combustion instability in guns as exhibited by pressure waves with high chamber pressures. If the pressures get too large for the particular gun design, the results are breechblows, ballistic variability, projectile prematures, fuze malfunctions, and possible fin damage to the new generation of projectiles currently being used and new ones being designed.

In a high-performance weapon such as a 120-mm or 105-mm gun (Figure 1), wherein maximizing muzzle velocity without exceeding specified maximum breech pressure limits is an ongoing requirement, small changes in charge and/or projectile configuration could lead to increased pressure wave problems which could increase chamber pressure beyond acceptable limits. Firings with projectile base configurations that protrude into the propellant bed, such as an M827 or M829, can influence initial ignition sequence in the densely-packed cartridge case resulting in an occasional firing having large pressure waves.

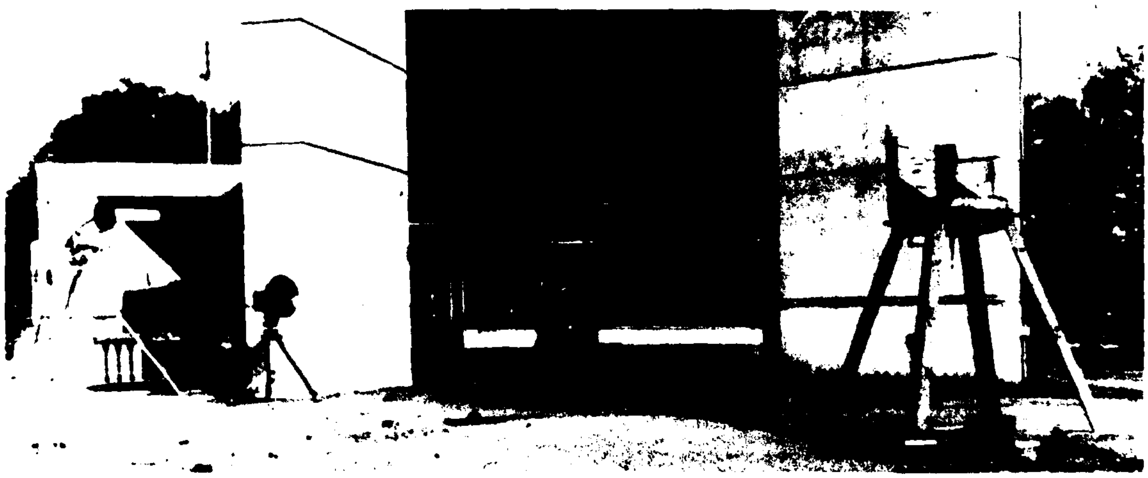


Figure 1. Typical 105-mm, M68 Gun Used in Firing Program

A comprehensive understanding of the nature of pressure waves in gun chamber volumes surrounding boattails and kinetic energy penetrators is critical to the design of high-performance propelling charges for such projectiles and to the assessment of safety for such rounds. Since both currently-used HEAT and kinetic energy ammunition in the 105-mm gun all have significant intrusion of projectile fins into the propellant bed requiring shortened ignition systems, slight changes in propellant, igniter or projectile base configuration might induce large pressure wave formation in this weapon system.

A study was done to provide experimental data to characterize both pressure gage placement with respect to boattail interface and pressure waves caused by these projectile systems that protrude into the gun chamber and propellant bed of the 105-mm gun. Data was acquired by test firings with both generic projectile base configurations with and without ullage and modified M489 projectiles to identify mechanisms that influence pressure waves during propellant charge ignition and early combustion.

II. TEST SETUP

A. Weapon

A 105-mm, M68 gun tube, Serial Number 31259, modified with pressure ports at three axial locations was the test weapon for all the firings. In order to measure system breech pressure, the standard M115 brass cartridge case was modified with two back-mounted, steel adapters for pressure gages without altering the threaded adapter port for the electric primer integral to the M115 case. An M158 recoil mechanism in conjunction with the upper cartridge from a 155-mm, M59 gun was used to mount the APG sleigh which housed the 105-mm, M68 Gun. All tests with this weapon were done at the Sandy Point Firing Facility (Range 18) located at the Ballistic Research Laboratory (BRL).

B. Instrumentation

Instrumentation on all tests consisted of eight Kistler 607C3 piezoelectric pressure transducers housed in the gun: five in the chamber, one downtube, and two in the base of the cartridge case (Figure 2). These gages (a redundant, cross-chamber gage at three positions) were sufficient to yield an approximation to the pressure-time/displacement profile in the chamber. By differencing either of the rear chamber with the forward chamber gages, the first negative pressure difference, $-\Delta P_i$, was determined. Since the forward chamber gages were at three slightly different locations, three slightly different $-\Delta P_i$ could be calculated (P1 - P2, P1 - P3, and P1 - P4).

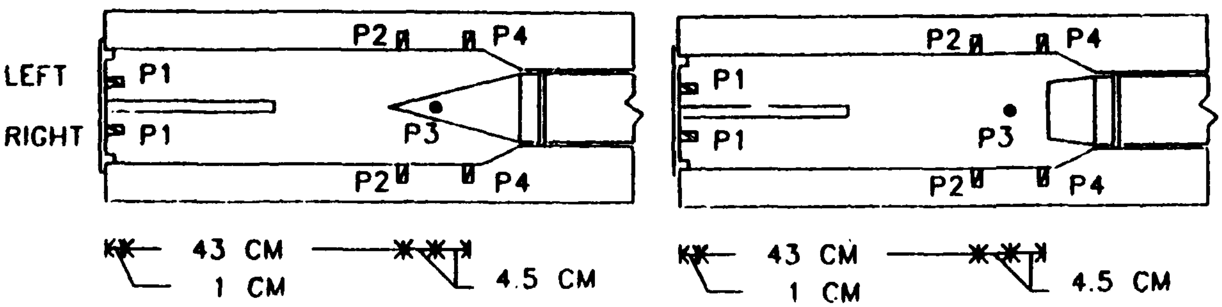


Figure 2. Locations of Pressure Transducers in the 105-mm, M68 Gun Chamber for Projectiles with Both Conical and Cylindrical Bases

Projectile displacement was determined by using a 15 GHz doppler radar to measure projectile motion both inbore and 10 metres beyond the gun muzzle. Projectile muzzle velocity was calculated by using the distance between a known time interval just after the projectile exited the gun tube. Ignition delay was determined by using the time interval from the application of the firing voltage to the M83 electrical primer (Lot LS-200-70) until the spindle pressure reached 7 MPa. Generally, the data were recorded in real time by the Ballistic Data Acquisition System (BALDAS) under the control of a PDP 11/45 minicomputer. If the data were not recorded online because of some unusual ignition delay or computer malfunction, they were later digitized from an analog tape recording made of each test firing.

C. Firing Components

T382-type projectiles fabricated in-house with base ends modified to take either a cylindrical or conical base extension were used for most tests (Figure 3). The generic projectiles were to simulate actual types as illustrated in the figure. The length of the cylindrical extension was determined such that this projectile would have the same volume as the one with the 15-cm long conical extension. All generic projectiles had both a nylon rotating band and forward bourrelet for maximizing obturation and minimizing balloting during in-tube travel. Projectile condition (burrs, indentations, etc.) and weight (6.85 ± 0.05 kg) were ascertained prior to loading and firing. M489 projectiles modified to give the same weight as the generic projectiles were used in the final phase of testing to ascertain the effects of fin versus generic base configuration on pressure wave formation.

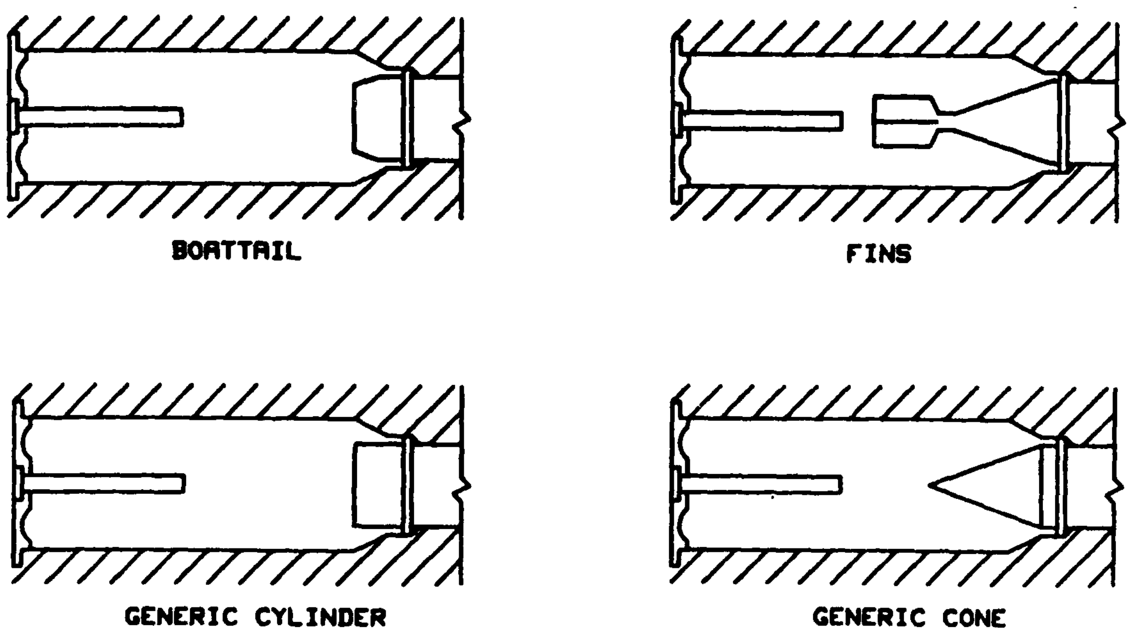


Figure 3. Projectile Types Used in Firings

The propelling charge was loaded into an M115 Brass Cartridge Case (Lot

NOR-5-10) containing both an M83 electrical primer and two Kistler pressure gages. The gages were housed in backmounted steel adapters in the base of the cartridge case (case cut down to expose the adapter) as illustrated in Figure 4. Prior to loading the propellant into the brass case, a titanium dioxide-impregnated liner (Lot IND 18-12) was glued into the case to minimize erosion of the gun tube.

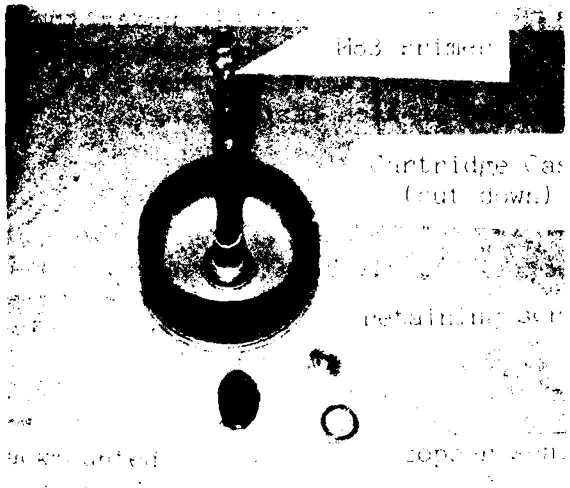


Figure 4. Technique for Backmounting Kistler Pressure Gages

III. RESULTS

A. Initial Selection of Propellant

Propellants used for this project are shown in Table 1. The initial rationale was to do tests with a single base propellant such as M1 and compare its response to that of a multiple base propellant such as M30 for a variety of test conditions. Using the inhouse IBHVG code[5], lumped-parameter, interior-ballistic simulations (Figure 5) were performed for each of these available granular propellants (Appendix A). Depending on the propellant type and web (Table 1), different charge weights were used. For the M30MP propellant, charge weight and web for charges fired with either axial or circumferential ullage containment were 4.65 kg and 1.02 mm, respectively; for charges fired completely filled (minimum axial or circumferential ullage containment), the charge weight and web were 5.78 kg and 1.22 mm, respectively. For the M1MP propellant in which only axial ullage confinement was done, the charge weight and web were 4.54 kg and 0.84 mm, respectively.

TABLE 1. Granular Multi-Perforated Propellants Used In Tests

Propellant	Web (mm)	Length (mm)	Diameter (mm)	Perf (mm)
M1MP	0.84	10.32	5.00	0.55
M30MP	1.02	13.28	5.54	0.48
M30MP	1.22	15.88	7.11	0.74

For the M1MP, 0.84-mm web propellant, both the pressure range and minimum loading constraint of 300-425 MPa and 4.55 kg, respectively, suggested its acceptability for the initial tests where both axial and circumferential ullage of 819 cc were to be the variables. For the maximum loading constraint where no ullage would be present, predicted pressure of 500 MPa was considerably above the upper pressure limit of 425 MPa. If, however, firing data tends to fall below predicted values or density-of-loading is less than that calculated, this web of propellant may be acceptable, at least for tests at 21° C. No other available M1MP propellant is of the proper web size to fall within the pressure range of 300-425 MPa.

For the M30MP propellant, two different webs were needed to bracket the pressure range with test conditions of 819 cc ullage and no ullage present. Whereas the M30MP, 1.02-mm web propellant was acceptable for ullage equal to 819 cc (predicted pressure of 420 MPa), its predicted pressure of 650 MPa with no ullage present was much too high for safe operation of the weapon. Conversely, for the M30MP, 1.22-mm web propellant, predicted pressure of 280 MPa, while low for an ullage condition of 819 cc, was, for no ullage present, well within the pressure range at 405 MPa.

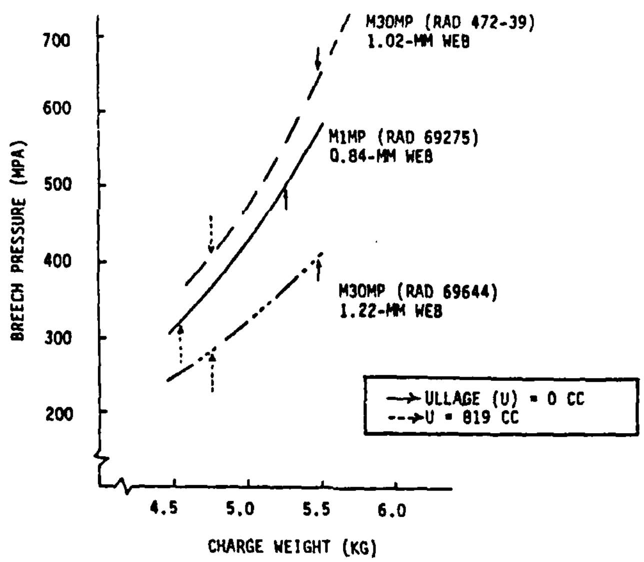


Figure 5. Simulations for M1MP and M30MP Propellant at Various Charge Loadings

B. Firings with M1MP, 0.84-mm Web Propellant

The initial firings with 0.84-mm web propellant were done with the propellant and all auxiliary components conditioned at 21° C for a minimum of 24 hours. Axially-confined propellant was used with projectiles having conical and cylindrical extensions on the projectile base (Figure 6). Confinement was achieved by using a cardboard disc and cylinder. The disc which covered the propellant was held at its proper axial location for the ullage desired by the cardboard cylinder inserted between the disc and the base of the projectile.

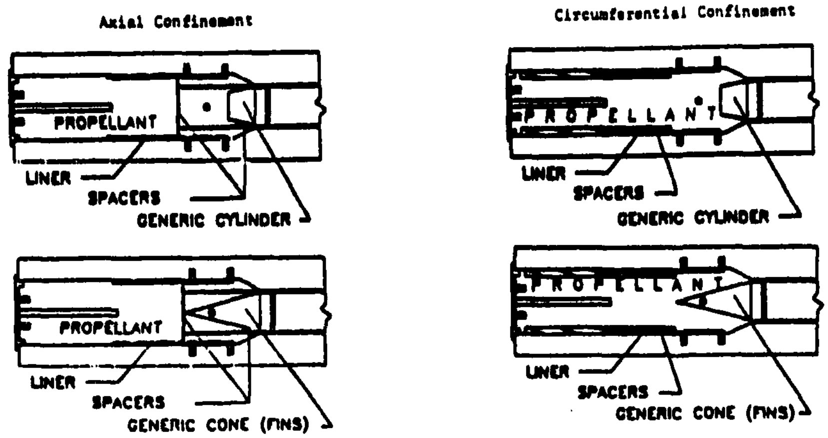


Figure 6. Axial and Circumferential Ullage Confinement for Projectiles with Both Conical And Cylindrical Base Extensions

Results for the six firings (three each for each base configuration) are listed in Table 2. As shown in the plots (Figure 7 and Appendix B) chamber

TABLE 2. Firing Results for Projectiles with Conical and Cylindrical Bases using M1MP, 0.84-mm Web Propellant at 21° C with a Standard M83 Primer**

Type Base	POS	P1	P2	P3	P4	P1-* P2	P1-* P3	P1-* P4	Vel.	Ig. Del.
		(-------	-------	MPa	-------	-------	-------	-------)	(m/s)	(ms)
CYL	R	---	323	304	307	19	20	26	1199	7
	L	331	304		301	15		19		
CYL	R	316	317	298	301	12	12	13	1202	7
	L	325	306		299	10		17		
CYL	R	321	321	300	304	13	12	19	1207	7
	L	331	---		302	9		16		
CONE	R	324	321	304	306	--	15	23	1207	7
	L	336	308		304	8		24		
CONE	R	322	326	300	304	16	12	20	1206	9
	L	330	307		299	11		15		
CONE	R	331	336	310	313	27	21	28	1208	7
	L	340	327		309	19		26		

*First negative pressure difference maximum for each set of gages

**Nominal weights for projectile and charge are 6.85 ± 0.05 kg and 4.54 ± 0.01 kg, respectively. All items conditioned for a minimum of 24 hours prior to firing. Charges were loaded with axial ullage present. Gage position P3 was at 12 o'clock. All others either right(R) or left(L).

pressure versus chamber position indicate the expected trend although since P2 is 45 cm from P1 and P2, P3, and P4 are each separated by only 4.5 cm (Figure 2), one would expect P2 to be closer in value to P3 and P4. Although the averaged pressure at each chamber location was higher for the conical-based projectiles, the differences were too small to be considered relevant since they are well within the round-to-round and gage-to-gage variations between the two types of projectiles. The pressure difference, $-\Delta P_i$, for any of the possible combinations (P1 - P2, P1 - P3, P1 - P4) indicated only minor differences between axial locations or projectile types.

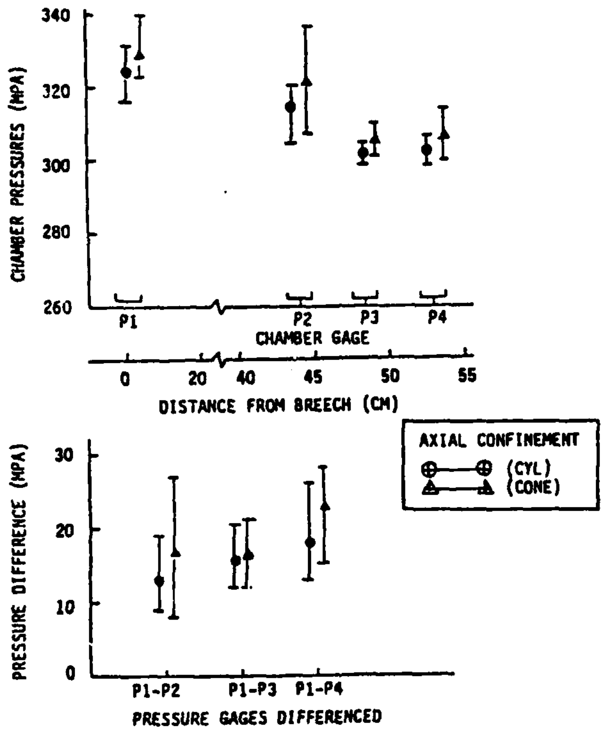


Figure 7. Firing Results for M1MP, 0.84-mm Web Propellant

Because the peak chamber pressures were higher than originally predicted with an ullage of 819 cc, several firings at various charge weights were done to ascertain if the predicted curve was essentially correct at the higher loading densities. Results (Figure 8) showed that both experimental pressures and the amount of propellant needed for a no ullage condition were considerably higher than predicted (625 MPa experimental versus 500 MPa predicted for a no ullage condition primarily because the case could hold 5.45 kg rather than the 5.25 kg predicted). Since these results precluded additional firings both with a no ullage condition and at elevated temperatures (63° C), no additional firings were done with M1MP propellant.

A typical plot for M1MP firings is shown in Figure 9. Maximum $-\Delta P_i$ occurred very early in the ignition process and damped out well before peak pressure was reached suggesting minimum feedback into the combustion process.

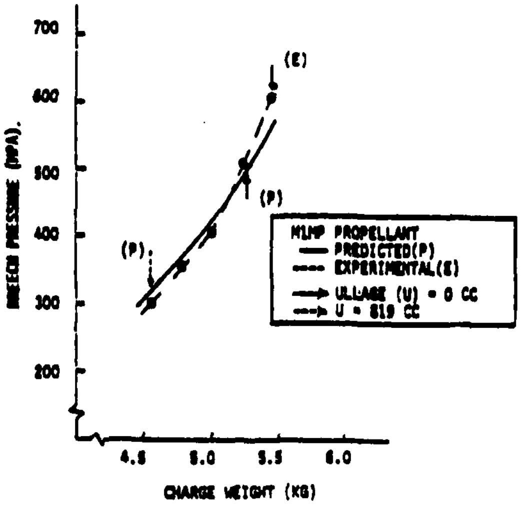


Figure 8. Predicted and Experimental Pressures versus Charge Weight

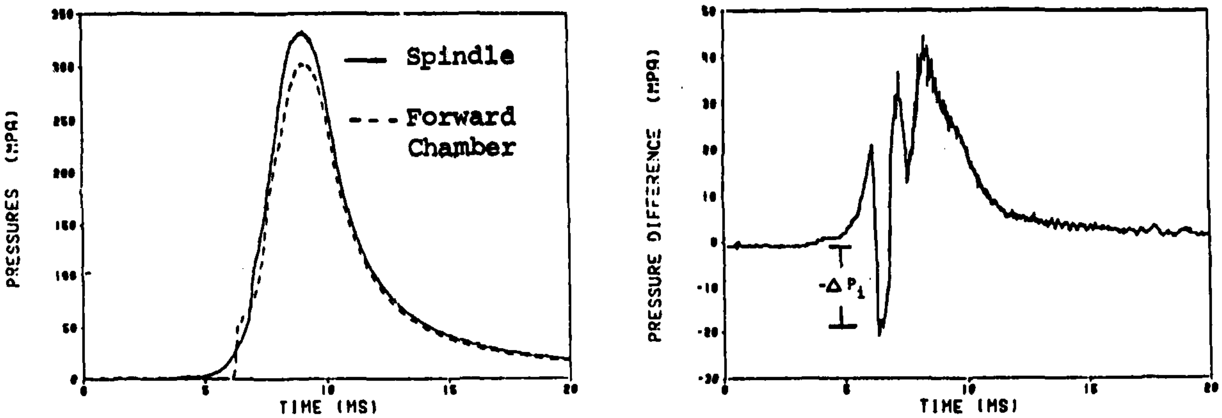


Figure 9. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M1MP, 0.84-mm Web Propellant at 21° C, Standard Primer, Cylindrical and/or Conical Bases

C. Firings with M30MP, 1.02-mm Web Propellant

Since no firings could be done at an elevated temperature of 63° C with this web of propellant because of the high pressures predicted, only firings at 21° C were done to compare with results obtained for M1MP. As in the previous tests, all components were conditioned at 21° C for at least 24 hours prior to firing. Both axially- and circumferentially-confined propellant was used with projectiles having both conical and cylindrical extensions on the projectile base (Figure 3). Axial confinement (axial ullage) was as described in the previous test with M1MP propellant except polyethylene foam was used in place of cardboard. Circumferential confinement (radial ullage) was achieved by making large cylinders of rigid polyethylene foam and placing them between the propellant and M115 case wall (Figure 6). This reduced slightly, the diameter of the propellant charge thus forcing it to fill out the total length of the volume between the base of the case and projectile. Results for the 14 firings are listed in Table 3 and Appendix B.

TABLE 3. Firing Results for Projectiles with Conical and Cylindrical Bases using M30MP, 1.02-MM Web Propellant at 21° C with a Standard M83 Primer**

TYPE BASE	POS	P1	P2	P3	P4	P1-* P2	P1-* P3	P1-* P4	Vel.	Ign. Del.
		(------	------	------	MPa	------	------	------)	(m/s)	(ms)
CYL(AX)	R	438	426	427	428	10	15	10	1348	--
	L	431	429		422	14		17		
CYL(AX)	R	446	432	432	434	10	14	13	1348	15
	L	439	439		421	14		12		
CYL(AX)	R	442	432	431	---	16	20	--	1338	17
	L	433	440		435	17		23		
CYL(AX)	R	459	435	440	426	14	18	14	1353	13
	L	443	440		416	15		17		
CONE(AX)	R	438	424	425	433	12	13	12	1338	17
	L	431	426		399	11		14		
CONE(AX)	R	439	425	422	427	9	10	12	1338	23
	L	433	427		405	10		14		
CONE(AX)	R	444	426	429	427	8	16	8	1341	18
	L	435	429		405	15		14		
CONE(AX)	R	434	418	419	410	11	15	16	1343	15
	L	426	412		405	17		18		
CYL(CR)	R	453	434	435	425	21	25	23	1368	18
	L	444	435		423	24		25		
CYL(CR)	R	444	---	428	422	--	22	21	1355	17
	L	432	406		428	24		22		
CYL(CR)	R	440	426	420	414	15	22	23	1351	18
	L	428	408		413	18		22		
CONE(CR)	R	448	436	433	421	11	21	21	1362	17
	L	439	429		422	17		25		
CONE(CR)	R	441	428	422	419	14	20	25	1358	18
	L	431	410		417	17		20		
CONE(CR)	R	442	426	422	416	15	22	23	1363	18
	L	432	411		417	18		23		

*First negative pressure difference maximum for different gages

**Nominal weights for projectile and charge are 6.85 ± 0.05 kg and 4.65 ± 0.01 kg, respectively. All items conditioned minimum of 24 hours prior to firing. Charges were loaded with both axial (AX) and circumferential (CR) ullage. Gage position P3 was at 12 o'clock. All others either right(R) or left(L).

The averaged pressures (Figure 10) for both the axially-confined and circumferentially-confined rounds with cylindrical base extensions are, essentially, the same. Both round-to-round and gage-to-gage variations within and between series suggest no difference in chamber pressure profiles. Within a particular ullage configuration, the $-\Delta P_i$ profiles indicate no difference between using conical or cylindrical base extensions. Although there is some difference in $-\Delta P_i$ between axially- and circumferentially- confined charges, the differences are, again, small in comparison to the large variations in pressure measurements. The indication (Table 3) that axial confinement results in smaller pressure waves than circumferential confinement is contrary to our understanding of the hydrodynamics involved and can be explained from our method of circumferential confinement (Figure 6). By not extending the circumferential wrap along the full length of the case, the 6 cm next to the projectile base had a higher loading density than the rest of the charge. This could have contributed to the level of pressure waves being greater.

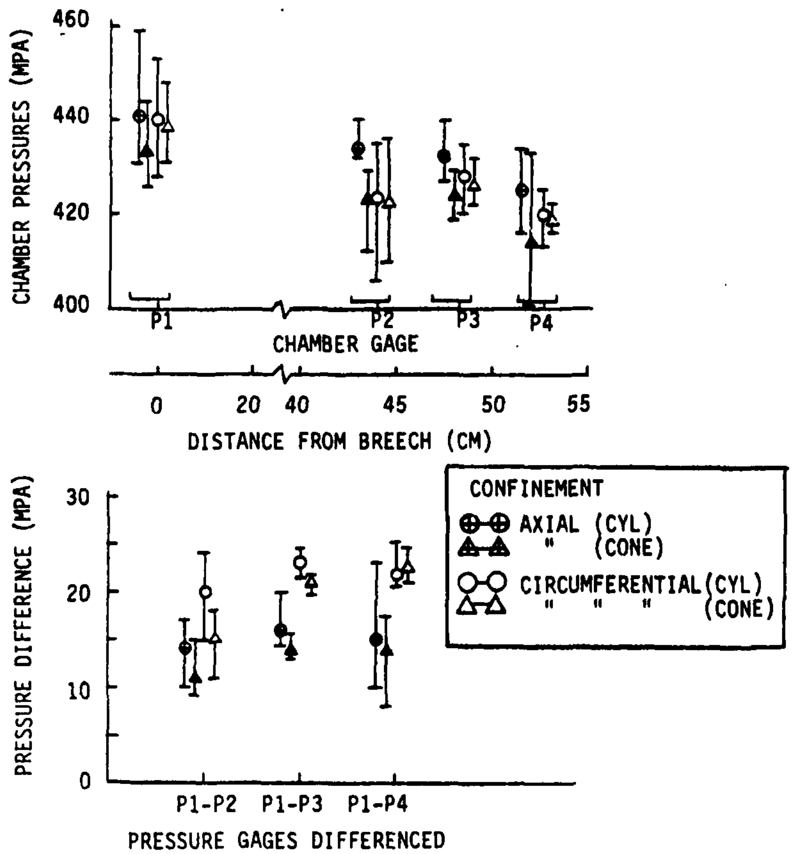


Figure 10. Firing Results for M30MP, 1.02-mm Web Propellant

As in the previous tests for M1MP and illustrated in Figure 11, $-\Delta P_i$ was essentially the same and did not feed back into the ballistic cycle even though the peak chamber pressure for the M30MP was 100 MPa higher than for the M1MP. Pressure and pressure difference versus time plots, shown in Figure 11 are typical for all firings for this web of M30MP propellant even though peak levels of pressure difference varied from 8 to 25 MPa.

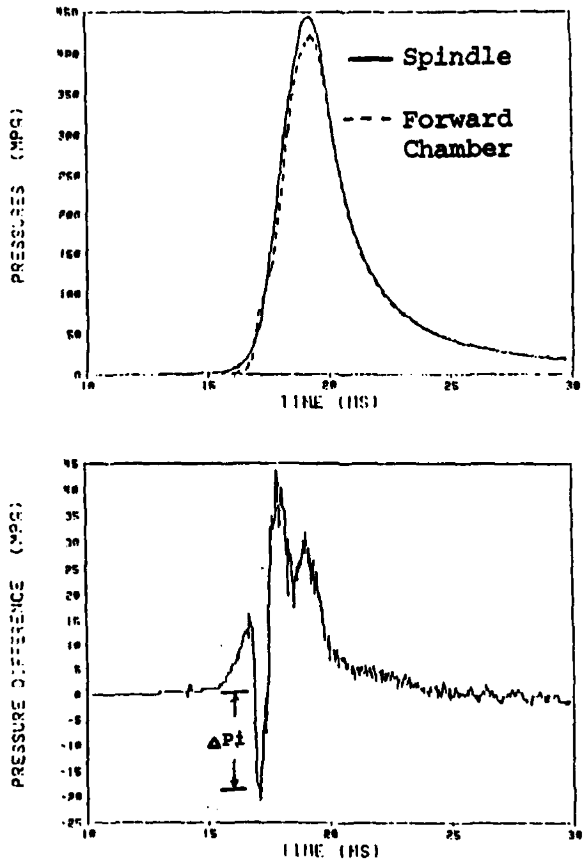


Figure 11. Typical Plots for Pressure and Pressure Difference versus Time for Firings with M30MP, 1.02-mm Web Propellant at 21° C, Standard Primer, Cylindrical and/or Conical Base

D. Firings with M30MP, 1.22-mm Web Propellant, Standard Primers

Predicted pressure versus charge weight indicated that chamber pressure would not be excessive for firings at an elevated temperature of 63° C. Therefore, firings with this propellant were done at three temperature extremes (-43° C, 21° C and 63° C) with the case completely filled with propellant (minimum axial and/or circumferential ullage). As in previous tests, all components except the projectiles were conditioned at their respective temperatures for at least 24 hours. Projectiles with both conical and cylindrical base extensions, regardless of propellant temperature conditioning, were kept at 21° C. Even for this no ullage condition that used a loose pack, 5.78 kg, rather than the 5.45 kg predicted, were needed to fill the case, thus making the actual peak pressures higher than those initially predicted.

Results for the firings at three temperature extremes (-43° C, 21° C and 63° C) for projectiles having conical and cylindrical base extensions are shown on the plots of Figure 12 and Appendix B and Tables 4, 5 and 6. A standard M83 primer was used to induce low-level pressure waves in the charges.

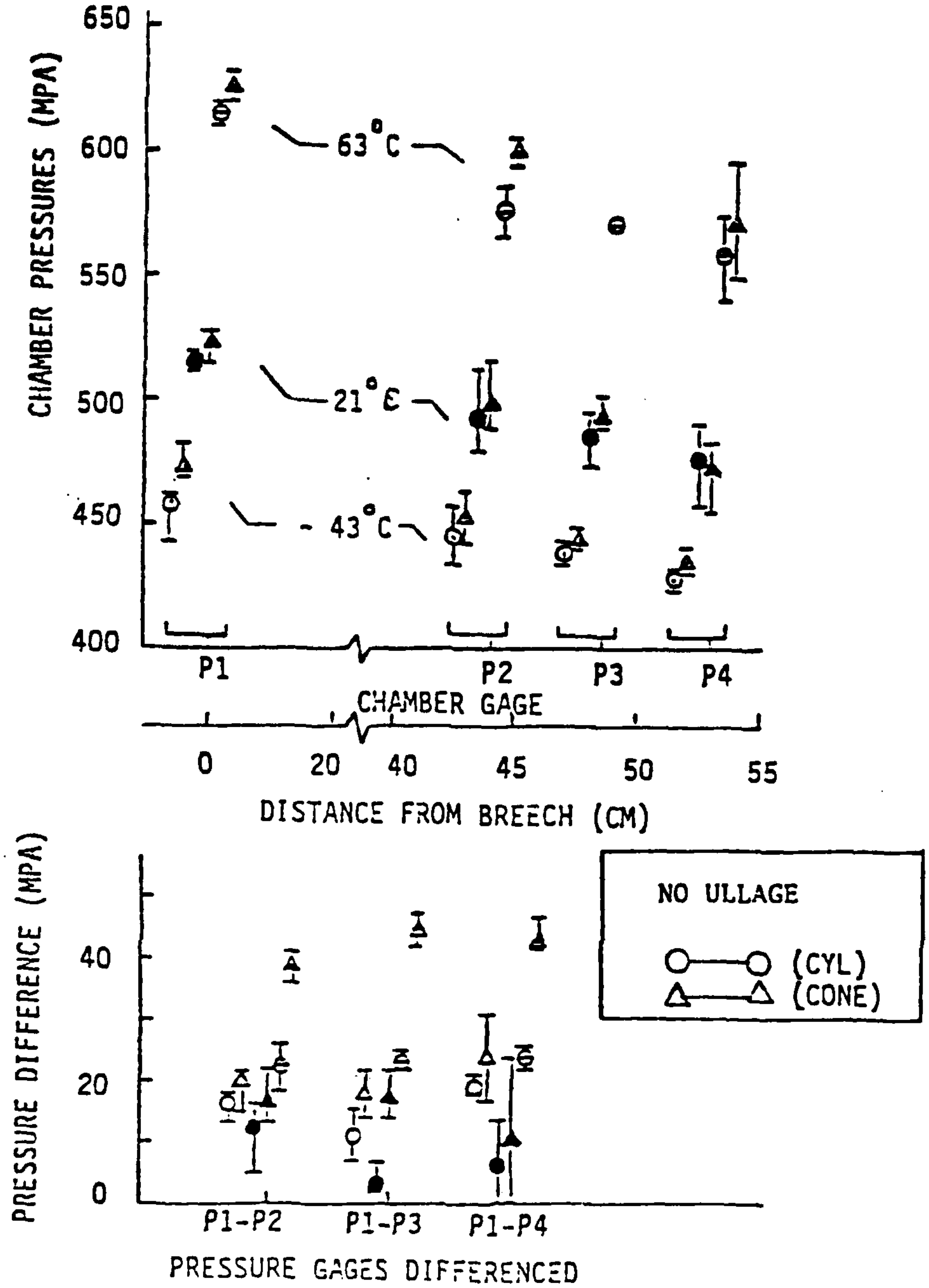


Figure 12. Firing Data for M30MP 1.22-mm Web Propellant

At each temperature condition, peak pressure was slightly higher for the rounds with conical base extensions. Chamber pressure distribution was normal, being highest at the spindle and lowest at the forward chamber position (Figure 12).

TABLE 4. Firing Results for Projectiles with Conical and Cylindrical Bases using M30MP, 1.22-mm Web Propellant at 21° C with a Standard M83 Primer**

TYPE BASE	POS	P1	P2	P3	P4	P1-* P2	P1-* P3	P1-* P4	Vel.	Ign. Del.
		(MPa						)	(m/s)	(ms)
CYL	R	511	490	---	476	14	--	1	1481	9
	L	516	500		483	14		12		
CYL	R	517	511	495	464	11	7	0	1487	12
	L	---	478		490	--		--		
CYL	R	516	494	474	456	11	2	0	1488	10
	L	516	487		491	9		12		
CONE	R	517	497	502	475	19	21	17	----	11
	L	521	497		480	20		24		
CONE	R	515	497	---	454	16	--	10	1485	9
	L	---	497		483	--		--		
CONE	R	524	515	488	463	18	14	0	1487	10
	L	528	488		483	13		0		

*First negative pressure difference maximum for different gages

**Nominal weights for projectiles and charges are 6.85 ± 0.05 kg and 5.78 ± 0.01 kg, respectively. Charges loaded with no ullage. Charges, cases, primers, propellant and projectiles were conditioned for 24 hours prior to firing. Gage position P3 was at 12 o'clock. All others either right(R) or left(L).

Averaged spindle pressure and chamber pressure of 518 MPa and 486 MPa (Table 4), respectively, for rounds fired with a standard M83 primer at 21° C were both considerably higher than the chamber pressures of 400 MPa predicted for, of course, a different charge loading. Although there was considerable pressure variation between rounds and gages, the averaged $-\Delta P_i$ for projectiles with conical bases was almost twice that of projectiles with cylindrical bases. This was the first indication that perhaps projectile base configuration may be important in inducing and/or supporting early combustion perturbations leading to pressure wave formation and that the gage location is important in accessing the level of delta pressure.

For rounds fired at -43° C, pressure and muzzle velocity, as expected, decreased, and ignition delay increased over that observed at ambient conditions. Even with the decrease in pressure level, the averaged $-\Delta P_i$ was

still slightly higher for conical base extensions over cylindrical base extensions. Again the projectile base configuration seems to be important.

TABLE 5. Firing results for Projectiles with Conical and Cylindrical Bases using M30MP, 1.22-MM Web Propellant at -43^{o} C with a Standard M83 Primer**

TYPE BASE	POS	P1	P2	P3	P4	P1-* P2	P1-* P3	P1-* P4	Vel.	Ign. Del.
		(-----------			MPa	---------------		-------)	(m/s)	(ms)
CYL	R	459	436	434	432	13	12	20	1423	14
	L	---	453		423	--		--		
CYL	R	464	434	441	429	13	13	15	1428	14
	L	460	454		428	18		20		
CYL	R	443	440	440	429	14	7	17	1424	14
	L	463	456		430	16		18		
CONE	R	472	442	445	437	16	18		1428	14
	L	470	461		438	20		24		
CONE	R	477	445	446	436	21	20	24	1424	16
	L	473	463		435	23		31		
CONE	R	472	447	441	432	21	16	21	1428	16
	L	482	457		432	18		23		

*First negative pressure difference maximum for different gages

**Nominal weights for projectiles and charges are 6.85 $\pm$ 0.05 kg and 5.78 $\pm$ 0.01 kg, respectively. Charges loaded with no ullage. Charges, cases, primers and propellant conditioned for 24 hours at -43^{o} C. All projectiles were conditioned at 21^{o} C for 24 hours. Gage position P3 was at 12 o'clock. All others were either right(R) or left(L).

For the two firings at 63^{o} C (Table 6), breech and chamber pressures for the conical base extension were larger than those for the cylindrical. Both pressure levels were higher than originally predicted because of the difference in the calculated versus actual charge loading. Although the conical base extension induced a considerably larger averaged $-\Delta P_i$ than the cylindrical base extension, it was not reflected in higher muzzle velocity. The large peak pressures coupled with the fairly large $-\Delta P_i$ cautioned us to discontinue these firings after only one round at each configuration because of the danger of tube and/or weapon component damage.

TABLE 6. Results for Projectiles with Conical and Cylindrical Bases using M30MP, 1.22-mm Web Propellant at 63° C with a Standard M83 Primer**

TYPE BASE	POS	P1	P2	P3	P4	P1-* P2	P1-* P3	P1-* P4	Vel.	Ign. Del.
		(----------MPa						----------)	(m/s)	(ms)
CYL	R	612	585	570	540	23	22	22	1539	8
	L	618	565		574	21		25		
CONE	R	620	605	---	549	41	42	40	1539	8
	L	631	593		595	40		47		

c

*First negative pressure difference maximum for different gages

**Nominal weights for projectiles and charges are 6.85 ± 0.05 kg and 5.78 ± 0.01 kg, respectively. Charges loaded with no ullage. Charges, cases, primers and propellant were conditioned for 24 hours at 63° C. All projectiles were conditioned at 21° C for 24 hours. Gage position P3 was at 12 o'clock. All Others were either right(R) or left(L).

Plots, typical of the cold and ambient series, are shown in Figures 13 and 14 for projectiles with cylindrical bases. For the hot series, plots for both the conical and cylindrical base configurations are shown since the difference in pressure wave level was considerable (Figures 15 and 16).

For firings at 63° C, the large difference in $-\Delta P_i$ between the projectiles with conical and cylindrical bases indicate that geometric shape may be important in inducing pressure wave formation in a round. The higher burning rate and reduced ignition time at the elevated temperature highlighted the differences between the two geometric base configurations. These changes, coupled with the differences in projectile/propellant geometry, seem to induce large pressure waves. Unfortunately, the large $-\Delta P_i$ and feedback into large chamber pressures at elevated propellant temperature prevented further testing in order to still insure gun integrity.

E. <u>Firings with M30MP, 1.22-mm Web Propellant, Modified Primers</u>

A test was devised wherein M83 primers were modified to induce medium to large pressure wave formation in an ambient charge completely filled with propellant (maximum axial and/or circumferential ullage) thus limiting the corresponding increase in peak pressure to an acceptable level. The modification consisted of reducing the length of the benite in the primer by thirds and replacing the missing benite with a wooden dowl. Thus a 1/3-benite primer gave more localized ignition than a 2/3- benite primer which gave more localized ignition than a standard primer (3/3- benite). By keeping the propellant at ambient conditions, any large $-\Delta P_i$ that might be induced would, hopefully, not be accompanied by extremely large peak pressures as a result of feedback from the induced $-\Delta P_i$. Results are listed in Table 7 and Appendix B.

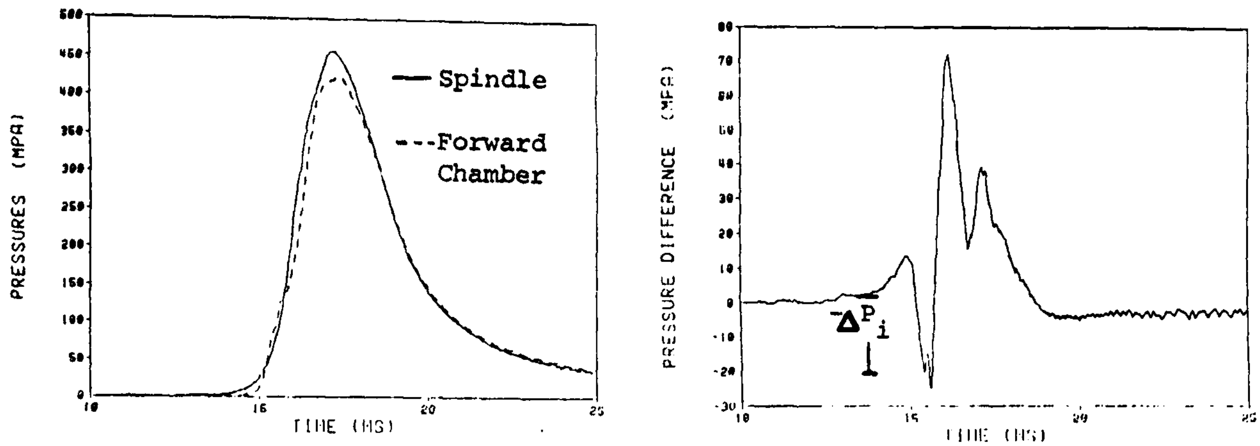


Figure 13. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at -43° C, Standard Primer, Cylindrical or Conical Base

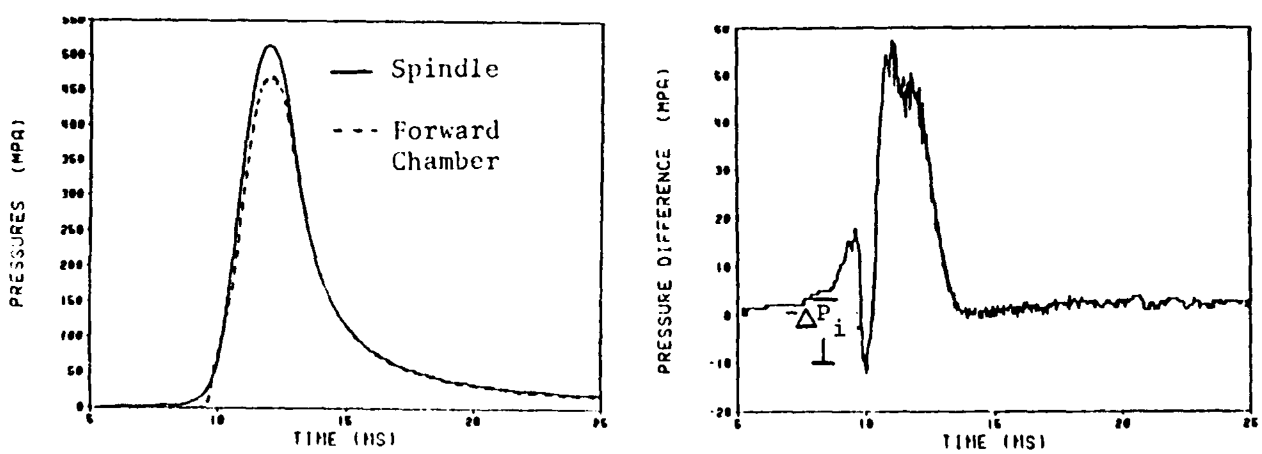


Figure 14. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 21° C, Standard Primer, Cylindrical or Conical Base

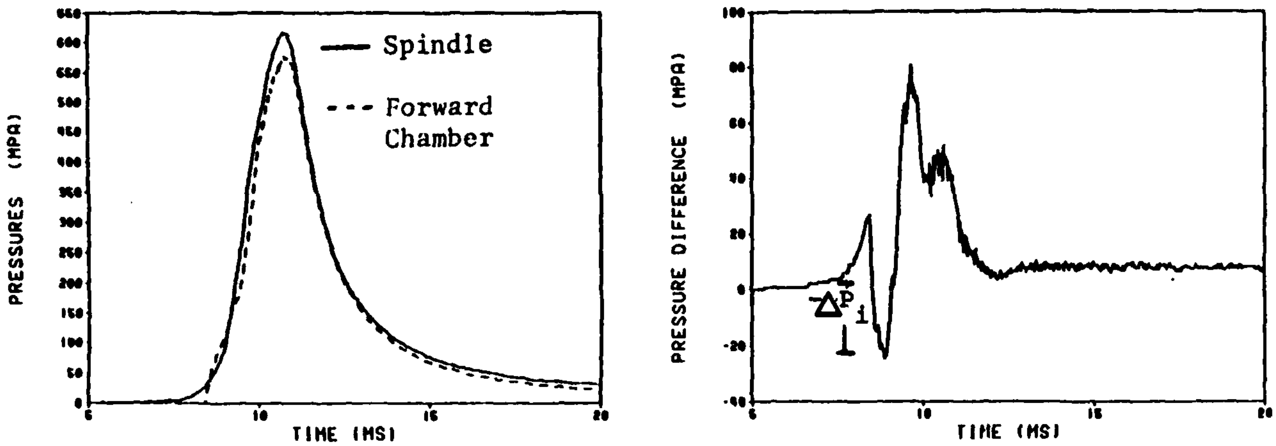


Figure 15. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 63° C, Standard Primer, Cylindrical Base

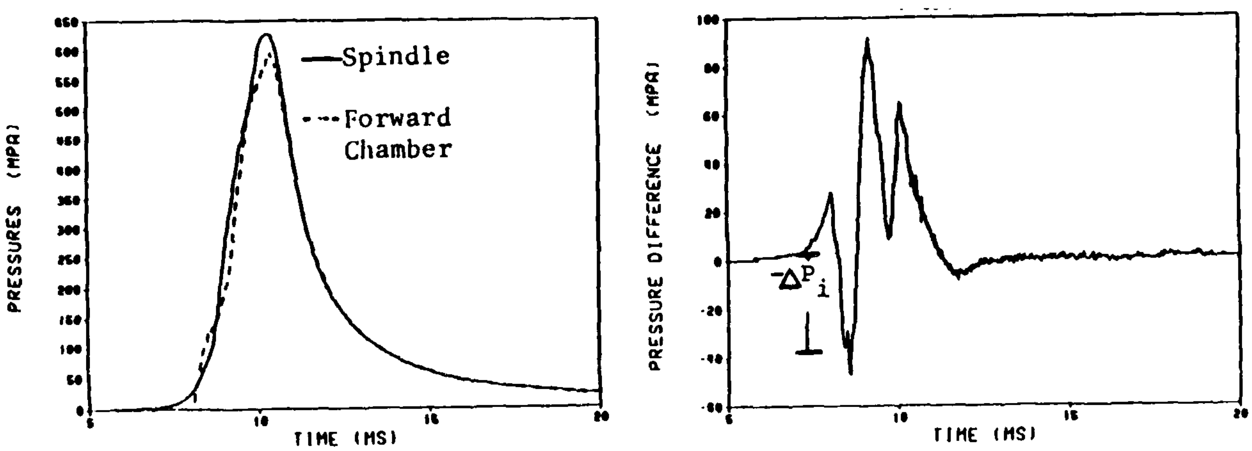


Figure 16. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 63° C, Standard Primer, Conical Base

TABLE 7. Firing Results for Projectiles with Conical and Cylindrical Bases using M30MP, 1.22-mm Web Propellant at 21° C with Modified M83 Primers**

TYPE BASE	PRIMER TYPE	POS	P1	P2	P3	P4	P1-* P2	P1-* P3	P1-* P4	Vel.	Ign. Del.
			(----------- MPa						-------------)	(m/s)	(ms)
CYL		R	508	---	477	467	--	9	5	1478	26
		L	505	486		463	3		15		
	Mod										
CYL	M83	R	505	481	481	472	36	18	33	1478	21
		L	506	483		469	29		25		
	2/3										
CYL	Benite	R	495	484	460	480	36	40	40	1504	24
		L	499	495		475	32		24		
	and										
CONE		R	519	500	486	483	55	38	36	1482	17
	1/3	L	521	498		479	51		67		
	wood										
CONE	dowl	R	547	528	494	507	83	62	98	1503	18
		L	542	534	494	511	83		99		
CONE		R	512	507	478	489	37	24	57	1483	23
		L	511	503		488	45		80		

CYL		R	---	518	487	496	58	32	87	1481	55
		L	518	531		493	55		79		
	Mod										
CYL	M83	R	---	461	452	448	--	42	--	1452	144
		L	465	477		454	41		60		
	1/3										
CYL	Benite	R	490	478	403	464	35	32	55	1453	106
		L	492	482		469	26		51		
	and										
CONE		R	589	548	522	533	105	122	158	1488	46
	2/3	L	592	547		528	110		144		
	wood										
CONE	dowl	R	528	511	482	488	76	35	119	1475	84
		L	533	522		491	81		94		
CONE		R	544	529	503	504	109	96	140	1487	49
		L	548	542		503	101		132		

*First negative pressure difference maximum for different gages

**Nominal weights for projectiles and charges are 6.85 ± 0.05 kg and 5.78 ± 0.01 kg, respectively. Charges loaded with no ullage. Charges, cases, primers, propellant and projectiles were conditioned for 24 hours prior to firing. Gage position P3 was at 12 o'clock. All others were either right(R) or left(L).

NOTE: Mod M83 Primers are fabricated so that all the Benite is at the rear of the primer and the forward space is filled with a wooden dowl

For the initial tests with the 2/3-benite filled primer, there was a large increase in averaged $-\Delta P_i$ over that with standard primers (Table 4). It increased by more than a factor of three for projectiles with cylindrical bases (25 versus 7 MPa) and by more than a factor of four for projectiles with conical bases (61 versus 14 MPa). There was also a two- to three-fold increase in ignition delay (24 and 19 ms, respectively, for cylinders and cones versus 10 ms for both configurations with standard M83 primers). For cylindrical bases, the averaged peak pressure and muzzle velocity of 503 MPa and 1478 m/s were similar to that with standard primers wherein the values were 515 MPa and 1485 m/s, respectively; with conical bases, the averaged peak pressure and muzzle velocity of 525 MPa and 1489 m/s were close to that observed with the standard M83 primers, 521 MPa and 1486 m/s, respectively. For projectiles with cylindrical bases, the increase in $-\Delta P_i$ over standard M83 primer firings did not feedback into peak pressure. For the second of three firings with conical bases, a large increase in $-\Delta P_i$ was accompanied by a large increase in peak pressure and muzzle velocity, perhaps another indication that projectile base geometry is important. Plots, typical of projectiles with conical and cylindrical bases are shown, respectively, in Figures 17 and 18.

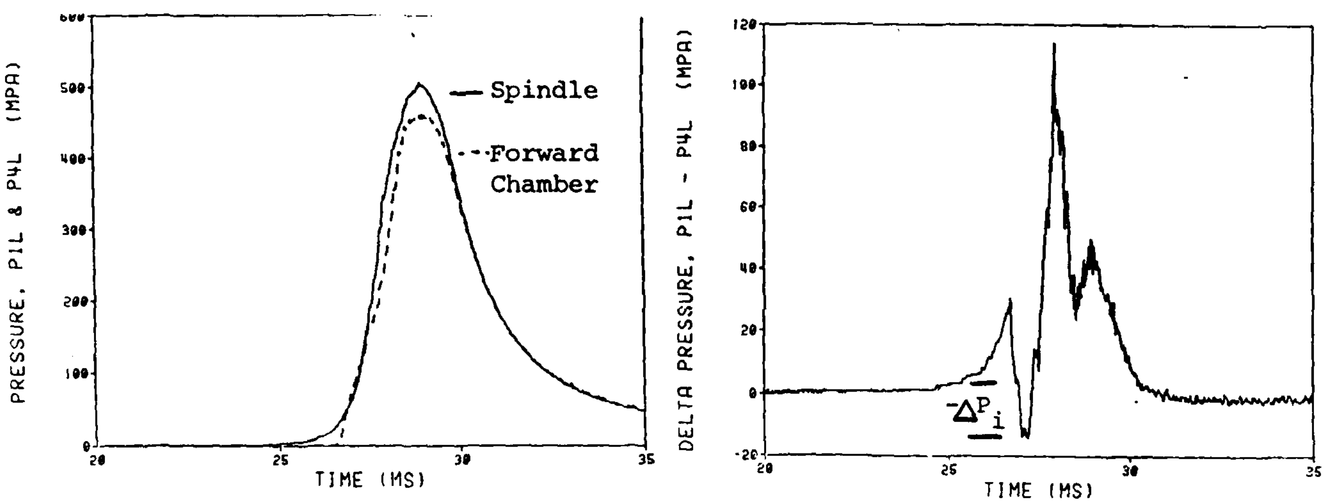


Figure 17. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 21° C, 2/3-Benite Modified Primer, Cylindrical Base

To ascertain the effects of a more localized ignition, a 1/3- benite filled primer was testfired with the two projectile configurations. There were noticeable differences between the two projectile types.

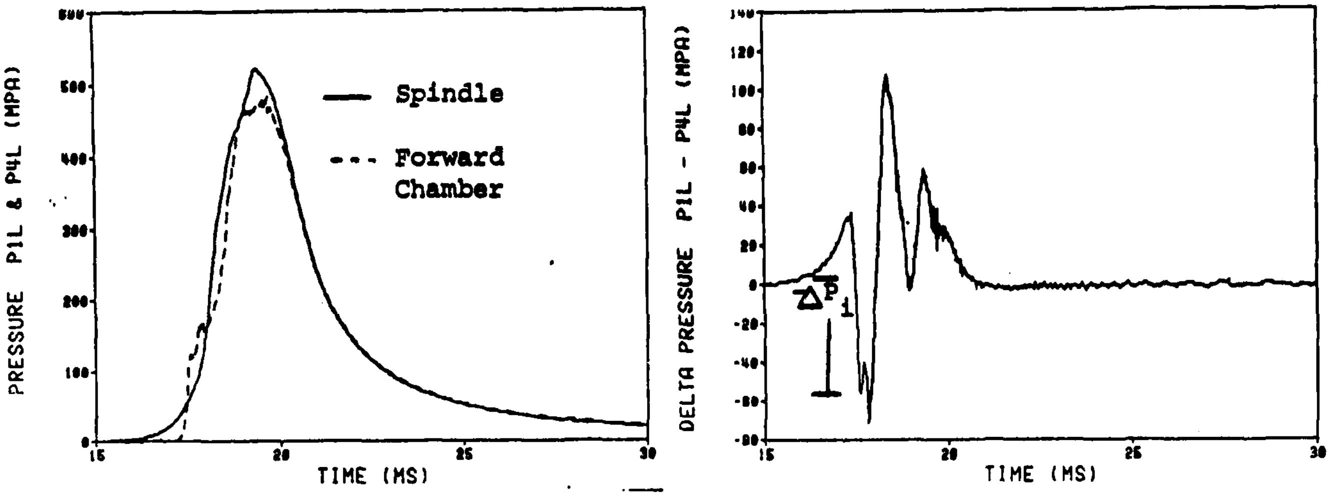


Figure 18. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 21° C, 2/3-Benite Modified Primer, Conical Base

For projectiles with cylindrical bases, the averaged - ΔP_i increased from 25 to 50 MPa over that observed in the previously described tests with a 2/3-benite filled primer. Averaged values for peak pressure and muzzle velocity decreased to 491 MPa and 1462 m/s, respectively, while ignition delay increased to 102 ms. Although the decrease in muzzle velocity followed the peak pressure decrease and thus was consistent, the lower pressure level with increasing $-\Delta P_i$ was not expected.

For projectiles with conical bases, the averaged $-\Delta P_i$ increased from 61 to 108 MPa, the averaged peak pressure increased from 525 to 556 MPa and the ignition delay increased from 19 ms to 60 ms for the 1/3-benite filled configuration over the 2/3-benite filled configuration. The averaged muzzle velocity of 1483 m/s was similar to that with the standard and a 2/3-benite filled primer. The expected increase in peak pressure for larger $-\Delta P_i$ did occur and may be geometry-related since it happened only for the projectiles with conical bases. An increase in ignition delay was expected for both modified primer types with the ignition delay longer for the more severely modified primers. Although the averaged peak chamber pressure for these rounds increased only 31 MPa to 556 MPa, thus not threatening gun integrity, one of the three rounds in this series reached a level of 590 MPa indicating some variability that might not be controllable. For this reason, we did not continue the tests with primers having less benite than a 1/3 configuration. Figures 19 and 20 show examples typical of both types of projectiles tested with a primer having a 1/3-benite filled configuration.

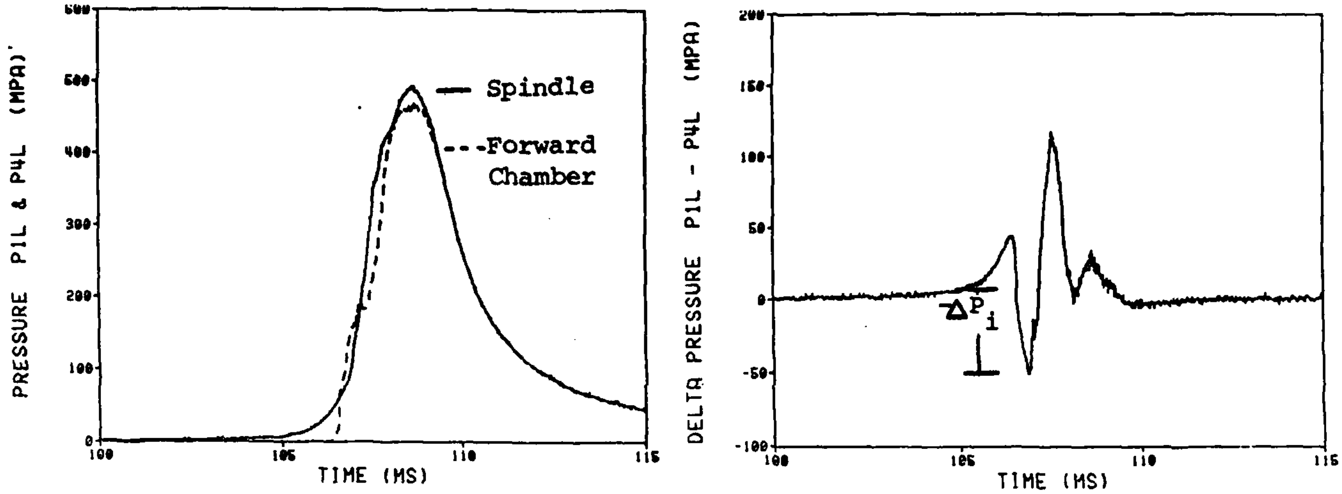


Figure 19. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 21° C, 1/3-Benite Modified Primer, Cylindrical Base

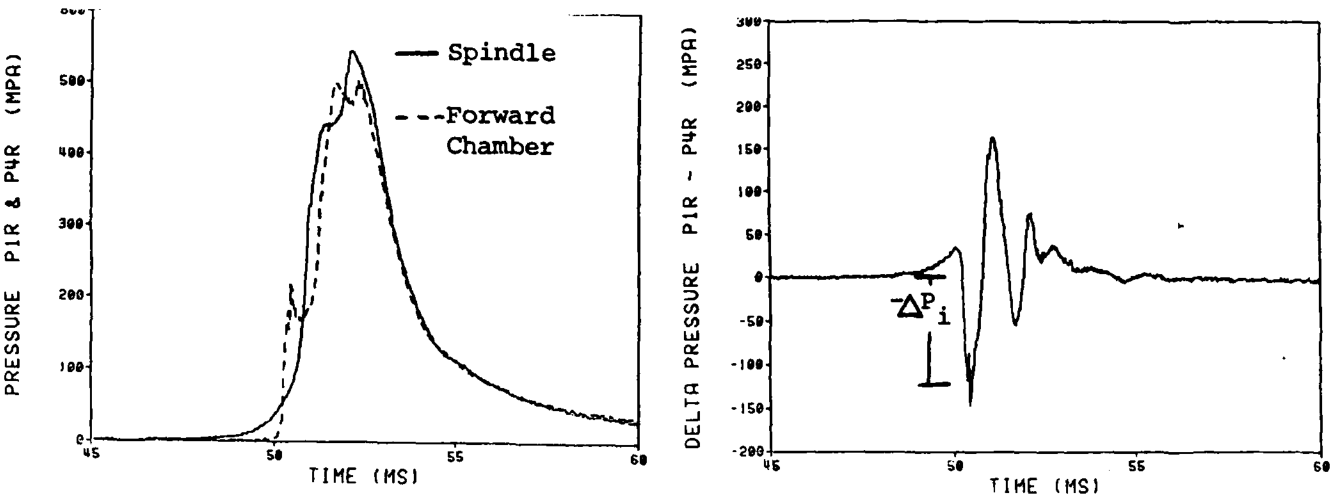


Figure 20. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 21° C, 1/3-Benite Modified Primer, Conical Base

The differences observed between the projectiles with cylindrical and conical bases prompted us to examine the initial ignition and early combustion effects on an M489 Projectile that had a conical boattail and a real fin (Figure 3). To keep approximately the same projectile weight as in the earlier configurations and still not alter the base-fin geometry, the forward cylindrical portion of the M489 was reduced in length by seven centimeters. Both standard and modified M83 primers were used in the tests. The decrease in chamber volume caused by the M489 fin necessitated reducing the propelling charge from 5.78 Kg to 5.67 Kg in order to maintain an ambient pressure level similar to that observed with the earlier projectiles having conical and cylindrical bases.

Results for the firings are listed in Table 8. The initial firings with the standard M83 primers at ambient conditions gave results similar to that observed for the projectiles with the conical and cylindrical base configurations. In comparing the data of Table 8 with that of Table 4, average spindle pressure at 500 MPa was lower than that observed for projectiles with cylindrical and conical base configurations (515 and 521 MPa, respectively) while muzzle velocity and ignition delay at 1490 m/s and 14 ms were both higher (1485 m/s and 10 ms for cylindrical bases and 1486 m/s and 10 ms for conical bases). The $-\Delta P_i$ variation of 0 to 31 MPa for modified M489s was larger than the 0 to 14 MPa for cylindrical bases and about the same as the 0 to 24 MPa for conical bases. In general, the averaged data for the M489s using standard primers (Figure 21) seems to be from the same population as that noted on Table 4 for the projectiles with conical and cylindrical bases.

TABLE 8. Firing Results for Altered M489 Projectiles using M30MP, 1.22-mm Web Propellant at 21° with Standard and Modified M83 Primers**

TYPE BASE	PRIMER TYPE	POS	P1	P2	P3	P4	P1-* P2	P1-* P3	P1-* P4	Vel	Ign. Del.
			(------------			MPa			---------------)	(m/s)	(ms)
Fin	Std	R	497	495	480	469	13	29	12	1484	14
	M83	L	508	471		466	21		31		
Fin	3/3	R	502	481	492	464	7	19	1	1494	16
	Benite	L	507	464		457	21		21		
Fin	0/3	R	493	488	475	454	11	15	0	1493	11
	Wood dowl	L	494	457		456	9		19		
Fin	Mod	R	---	588	582	558	---	129	---	1519	15
	M83	L	606	---	588	566	122		141		
Fin	2/3	R	564	550	541	522	110	122	121	1501	13
	Benite	L	558	498		541	125		115		
Fin	1/3	R	624	594	580	570	128	143	150	1517	18
	Wood	L	612	542		571	127		147		

*First negative pressure difference maximum for different gages

**Nominal weights for projectiles and charges are 6.85 ± 0.05 kg and 5.67 ± 0.01 kg, respectively except for round two of the 1/3-benite filled primer wherein the charge weight was 5.60 ± 0.01 kg. Gage position P3 was at 12 o'clock. All others either right(R) or left(L).

Results changed dramatically when going from the standard M83 to the 2/3-benite filled primer. All parameter averages except ignition delay at 15 ms increased significantly. In comparison to the data with a standard M83 Primer, peak pressure at 593 MPa was 18 percent higher, $-\Delta P_i$ at 129 Mpa was a huge 760 percent higher, and muzzle velocity at 1512 m/s was 1.4 percent higher.

The averaged values for pressure, - ΔP_i, and muzzle velocity exceeded even that for projectiles with conical and cylindrical base configurations wherein 1/3-benite filled primer ignition was used. The high peak pressure combined with the very high -ΔP_i (Figure 22) prevented us from doing tests with the 1/3-benite filled primer and a modified M489 projectile.

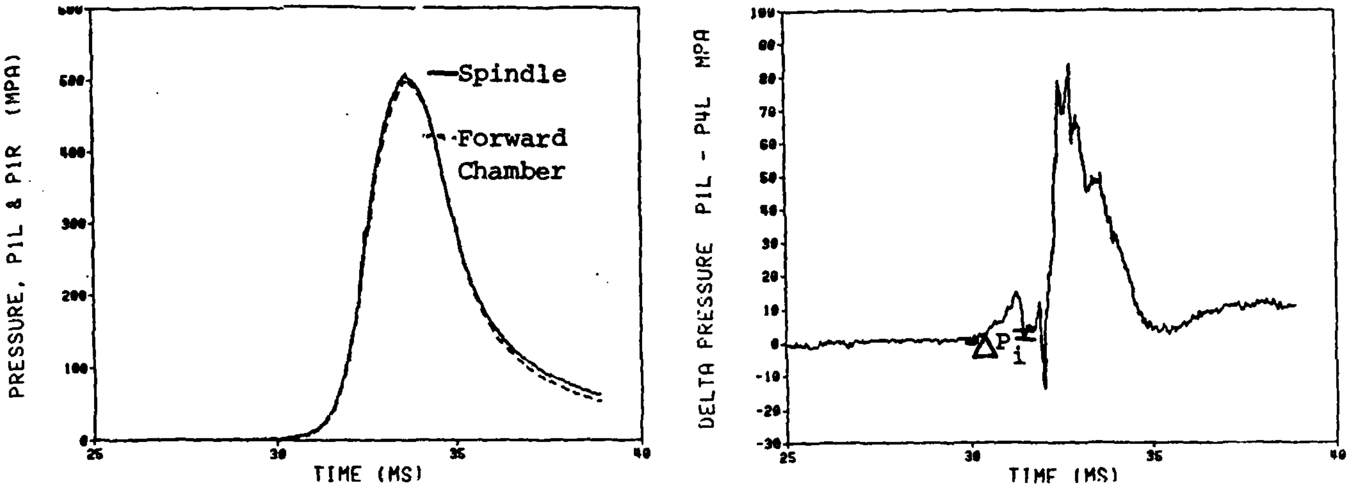


Figure 21. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 21° C, Standard Primer, Fin Base

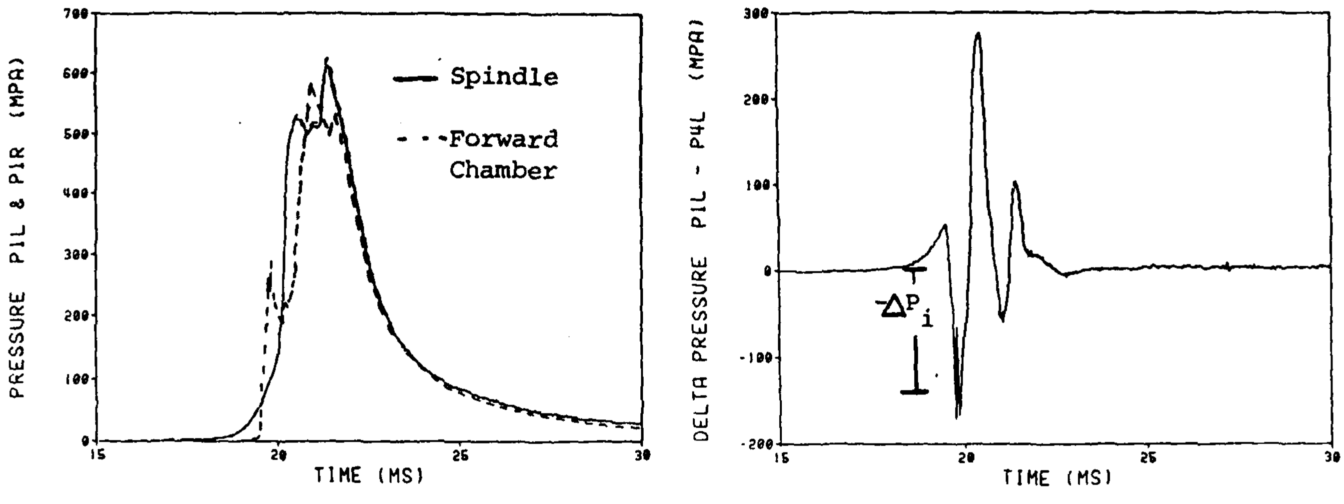


Figure 22. Typical Plots for Pressure and Pressure Difference Versus Time for Firings with M30MP, 1.22-mm Web Propellant at 21° C, 2/3-Benite Modified Primer, Fin Base

IV. CONCLUSIONS

The data base, although limited in size, suggests that the gage position with respect to the rear of the projectile is not critical in assessing the level of $-\Delta P_i$ regardless of base configuration. Considering the different types of base configurations (cylindrical, conical and fin), the amount of extension of projectile into the gun chamber and the gage-chamber interface clearance for different gage positions, one might have expected greater differences.

For the tests at 21° C and -43° C where standard M83 Primers were used, there was no significant pressure difference noted between the projectiles with conical, cylindrical or fin base extensions. At an elevated temperature of 63° C, geometric base shape did make a difference. The $-\Delta P_i$ for the projectile with a conical base was twice that of the projectile with a cylindrical base. However, because of the base chamber pressure level, sample size was limited to one round at each configuration.

When the M83 Primer was altered somewhat, the $-\Delta P_i$ difference between projectiles with conical and cylindrical bases was large even with ambient propellant. Although $-\Delta P_i$ got larger with increased alteration of the primer (standard to 2/3-benite to 1/3- benite), the conical to cylindrical ratio remained unchanged for the two modified primer configurations, increasing from one for the unmodified primer to approximately two for both the 2/3-benite filled and 1/3-benite filled primer configurations. For the modified M489 with actual fin configurations extending into the propellant bed, $-\Delta P_i$ increased dramatically from 8 MPa to approximately 129 MPa for the 2/3-benite primer, a ratio of altered to unaltered primer of 8.

A valid pressure wave safety assessment demands that sensitivity tests (maximum pressure versus $-\Delta P_i$) must be conducted with projectiles that have the same base configuration as the actual projectiles that are used in the population tests.

REFERENCES

1. I. W. May, "The Role of Ignition and Combustion in Gun Propulsion: A Survey of Developmental Efforts," Thirteenth JANNAF Combustion Meeting, Chemical Propulsion Information Agency, Laurel, MD, Publ, 281, September 1976.

2. A. W. Horst, T. C. Smith and S. E. Mitchell, "Experimental Evaluation of Three Concepts for Reducing Pressure Wave Phenomena in Navy 5-inch, 54-Caliber Guns: Summary of Firing Data," Naval Ordnance Station, Indian Head, MD, MR-76-258, August 1976.

3. A. W. Horst, I. W. May, and E. V. Clarke,Jr., "The Missing Link between Pressure Waves and Breechblows," Ballistic Research Laboratory, Aberdeen Proving Ground, MD, ARBRL-BR-02849, July 1978, (AD #A058354).

4. I. W. May and A. W. Horst, "Charge Design Considerations and Their Effect on Pressure Waves in Guns," Ballistic Research Laboratory, Aberdeen Proving Ground, MD, ARBRL-TR-02277, December 1980 (ADA095342).

5. P. G. Baer, "Practical Interior Ballistic Analysis of Guns," Interior Ballistics of Guns, M. Summerfield and H. Krier, Ed., Progress in Astronautics and Aeronautics, Vol. 66.

APPENDIX A

Description Sheets for M1MP and M30MP Propellants

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD- 69275 of 19 74 Composition No. M1, MP, 155MM HOW., FOR PROPELLING CHARGE, M4A2
ITEM V3-30623

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 461,487 LBS.

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. MIL-P-60397 (MU) W/EOPA'S 49906-2, 51949-2, 52153-2, 53472-2, PAN 7000588-2 AND TWX SMUAP-AMM-82142088

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

B-12,223Y; 231Y; 237Y; 252Y; 253Y; 256Y; 260Y;
261Y; 262Y; 263Y; 268Y; 282Y; 288Y; 295Y;
338Y

Y DESIGNATES WOOD SULFITE CELLULOSE

	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum	13.20 %	45+ Mins	30 + Mins
Minimum	13.11 %	Mins	30 Mins
Average	13.16 %	Mins	30 + Mins
Explosion			Mins

MANUFACTURE OF PROPELLANT

0.62 Pounds Solvent per Pound XX / Dry Weight Ingredients Consisting of 35 Pounds Alcohol and 65 Pounds ETHER per 100 Pounds Solvent.

Percentage Remix to Whole 10

PROCESS-SOLVENT RECOVERY AND DRYING

Temperatures °C From	To		Time Days	Hours
	35	LOAD SOLVENT RECOVERY TANK		
35	55	INCREASE SOLVENT RECOVERY TEMPERATURE		12
	55	HOLD SOLVENT RECOVERY TEMPERATURE		24
	65	WATER DRY CYCLE	4	
	55	AIR DRY CYCLE		16

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION *

Constituent	Percent Formula	Percent Tolerance	Percent Measured
NITROCELLULOSE	85.00	±2.00	84.97
DINITROTOLUENE	10.00	±2.00	9.73
DIBUTYLPHTHALATE	5.00	±1.00	5.30
TOTAL	100.00		100.00
DIPHENYLAMINE (ADDED)	1.00	±0.10	1.08
POTASSIUM SULFATE (ADDED)	1.00	±0.30	1.10
TOTAL VOLATILES			0.79
MOISTURE	0.60	±0.20	0.45
RESIDUAL SOLVENTS	1.32	MAX.	0.34

*COMPUTED ON TV-, DIPHENYLAMINE-, AND POTASSIUM SULFATE-FREE BASIS.

STABILITY AND PHYSICAL TESTS

	Formula	Actual
Heat Test S.P., 134.5°C	NO CC 40'	60'
NO EXPLOSION	5 HRS. MIN	5 hrs.
Form of Propellant		GRAIN TYPE I
NO. OF PERFORATIONS		7
COMPRESSIBILITY	30% MIN	43

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD- 69275	+90	99.62 %	99.85 %
Standard	RAD-68308	+90	100.00%	100.00%

Remarks

FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1, IN A NOMINAL SIZE 200 CC CLOSED BOMB. TEST FOR INFORMATIONAL PURPOSES ONLY.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)		0.447	0.4322	6.25 MAX.	1.73
Diameter (D)		0.279	0.1943	6.25 MAX.	2.66
Perf Dia. (d)		0.023	0.0152		
WEB					
INNER		0.0535	0.0361		
OUTER		0.0515	0.0387		
AVERAGE		0.0525	0.0374		
Web Difference/Variation in % of Web Average	15 MAX.		7.1		
L/D	2.10 to 2.50		2.22		
D/d	5.0 to 15		12.8		

DATES

Packed	4/22/74
Samples	4/22/74
Test Finished	4-29-74
Offered	4-30-74
Description Sheets Forwarded	5-2-74

Type of Packing Container FIBER DRUMS PER MIL-STD-652B

Remarks

THIS LOT MEETS ALL THE CHEMICAL AND PHYSICAL REQUIREMENTS OF THE APPLICABLE SPECIFICATION.

Contractor's Representative
H. C. Dickinson H.C. Dickinson

Government Quality Assurance Representative
for JAMES E. BLAND [signature]

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD-PE-472-39 of 1977 Composition No. M30 Propellant f/105mm UPGUN

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount ?,129 lbs

Contract No. DAAA09-77-C-4007 Date 4-1-77 Specification No. COR ltr, SARRA-IE, dtd April 11, 1977

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

C-35,659

Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum — %	— Mins.	— Mins.
Minimum — %	— Mins.	— Mins.
Average 12.59 %	45+ Mins.	30+ Mins.
		Explosion — Mins.

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound NC XX Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds ACETONE per 100 Pounds Solvent.

Percentage Remix in Whole 25

Temperatures °F From	Temperatures °F To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Time Hours
		LOAD FORCED AIR DRY AT AMBIENT TEMPERATURE		
AMBIENT	140	INCREASE TEMPERATURE 5°F PER HOUR		12
140	140	HOLD AT TEMPERATURE		40

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION / STABILITY AND PHYSICAL TESTS

Constituent	Percent Formula	Percent Tolerance	Percent Measured		Formula	Actual
NITROCELLULOSE	28.00	± 1.30	28.65	Heat Test S.P., 120°C	NO CC 60'	60'
NITROGLYCERIN	22.50	± 1.00	21.98	NO FUMES	—	60'
NITROGUANIDINE	47.70	± 1.00	47.48	Form of Propellant		Cylindrical
ETHYL CENTRALITE	1.50	± 0.10	1.57	NO. OF PERFORATIONS	7	7
CRYOLITE	0.30	± 0.10	0.32			
TOTAL	100.00		100.00			
TOTAL VOLATILES	0.50	MAX.	0.19	Absolute Density		1.677 gm/cc
GRAPHITE GLAZE	0.2	MAX.	0.13			

CLOSED BOMB

	Lot Number	Temp. °F	Relative Quickness	Relative Force
Test	PE-472-39	+90	113.27%	100.57%
	PE-472-39	-40	109.24%	99.21%
Standard	RAD-67878	+90	100.00%	100.00%
Remarks				

PROPELLANT DIMENSIONS (inches)

	Specification *	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)		0.461	0.472	5.25 MAX	1.12
Diameter (D)		0.260	0.2259	3.125 MAX	1.18
Perf. Dia. (d)		0.027	0.0235		
WEB					
INNER	0.040	0.0450	0.0394		
OUTER	0.040	0.0445	0.0395		
AVERAGE	0.040	0.045	0.035		
Web Difference/ Max. Dev. in % of Web Average	15% MAX.		0.30		
L:D	2.0, nom		2.09		
D:d	5.0 to 15		9.62		

DATES	
Packed	9-15-77
Sampled	9-15-77
Test Finished	9-27-77
Offered	
Description Sheets Forwarded	

Type of Packing Container Fiber Drums: 13 @ 160 lbs net; 1 @ 34 lbs net

Remarks

*Nominal requirement.

This lot meets all chemical and physical requirements of the required specification.

Contractor's Representative R. J. Re[illegible]

Government Quality Assurance Representative James E. Bland
JAMES E. BLAND

PROPELLANT DESCRIPTION SHEET Library file copy

U.S. Army Lot No. RAD77E-069644 Composition No. M30 f/105mm, for Ctg., APFSDS-T, M735

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 301,985 lbs
Contract No. DAAA09-77-C-4007 Date 4-1-77 Specification No. MIL-P-63105

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

C-35,400; 458; 465; 466; 468; 472; 475; 480;
481; 488; 490

	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum	12.68 %	Mins.	Mins.
Minimum	12.56 %	Mins.	Mins.
Average	12.60 %	45+ Mins.	30+ Mins.
			Explosion Mins.

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound ~~NC~~/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent.

Percentage Remix to Whole 25

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
		LOAD FORCED AIR DRY AT AMBIENT TEMPERATURE		
AMBIENT	140	INCREASE TEMPERATURE 5°F PER HOUR		
140	140	HOLD AT TEMPERATURE		40

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION — STABILITY AND PHYSICAL TESTS

Constituent	Percent Formula	Percent Tolerance	Percent Measured		Formula	Actual
NITROCELLULOSE	28.00	±1.30	28.66	Heat Test S.P., 120°C	NO CC 40'	60'
NITROGLYCERIN	22.50	±1.00	22.31	NO FUMES	- - - -	60'
NITROGUANIDINE	47.70	±1.00	47.17	Form of Propellant TYPE I		CYLINDER
ETHYL CENTRALITE	1.50	±0.10	1.55	NO. OF PERFORATIONS		7
CRYOLITE	0.30	±0.10	0.31			
TOTAL	100.00		100.00			
TOTAL VOLATILES	0.50	MAX.	0.24			
GRAPHITE GLAZE	0.2	MAX.	0.13			

CLOSED BOMB

	Lot Number	Temp. °F	Relative Quickness	Relative Force
Test	RAD77E-069644	+90	96.38 %	99.99 %
	RAD77E-069644	-40	92.80 %	98.24 %
Standard	RAD-67878		100.00%	100.00%

Remarks

FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1, IN A NOMINAL SIZE 200 CC CLOSED BOMB. TEST FOR INFORMATIONAL PURPOSES ONLY.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)		0.650	0.6594	6.25 MAX.	0.95
Diameter (D)		0.316	0.2761	3.125 MAX	1.22
Perf. Dia. (d)		0.032	0.0283		
WEB					
INNER		0.0560	0.0480		
OUTER		0.0540	0.0485		
AVERAGE		0.0550	0.0483		
Web Difference/ of Web Average			-		
L:D	2.10 to 2.50		2.39		
D:d	5.0 to 15		9.8		

DATES

Packed 5-27-77
Sampled 5-27-77
Test Finished 6-9-77
Description Sheets Forwarded 6-14-77

667 M24 Containers per Dwg. 76-4-46
1262 Fiber Drums per MIL-STD-652C with Notice 1

... CHEMICAL AND PHYSICAL REQUIREMENTS OF THE APPLICABLE SPECIFICATION.

H. C. Dickinson for

Government Quality Assurance Representative

JAMES E. BLAND

Rev. 4 (3/77)

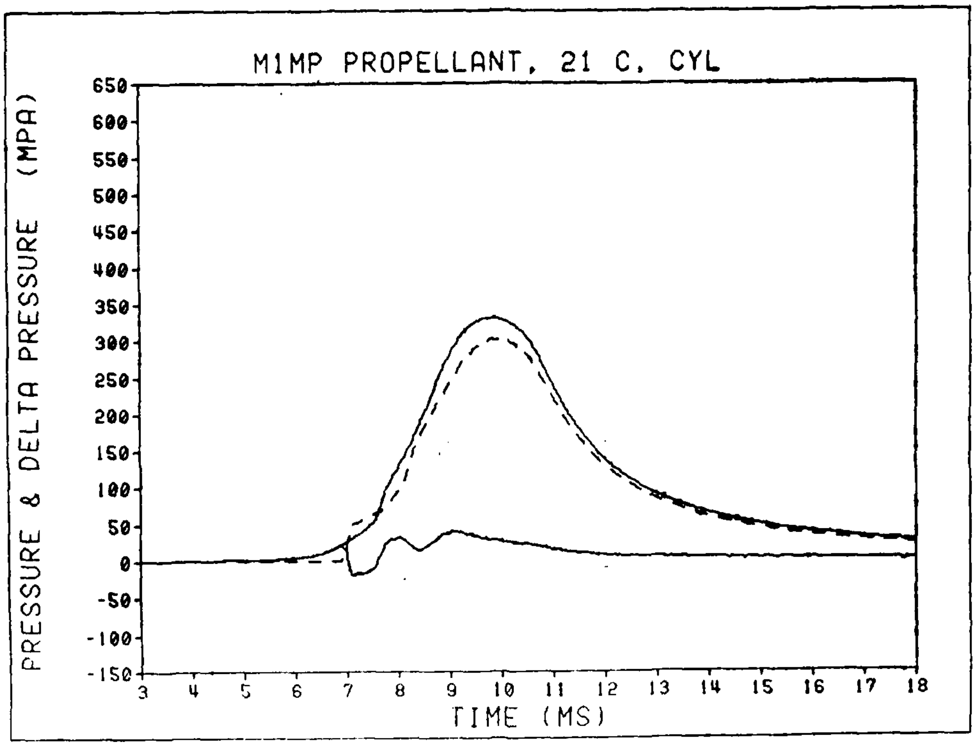
APPENDIX B

Computer generated plots for Selected Data Channels
of Spindle Pressure (solid line), Forward Chamber Pressure (dotted line)
and Pressure Difference (solid line)
Versus Time

(Plots are listed in the order they appear in the report tables)

APPENDIX INDEX

APPENDIX INDEX (CONT'D)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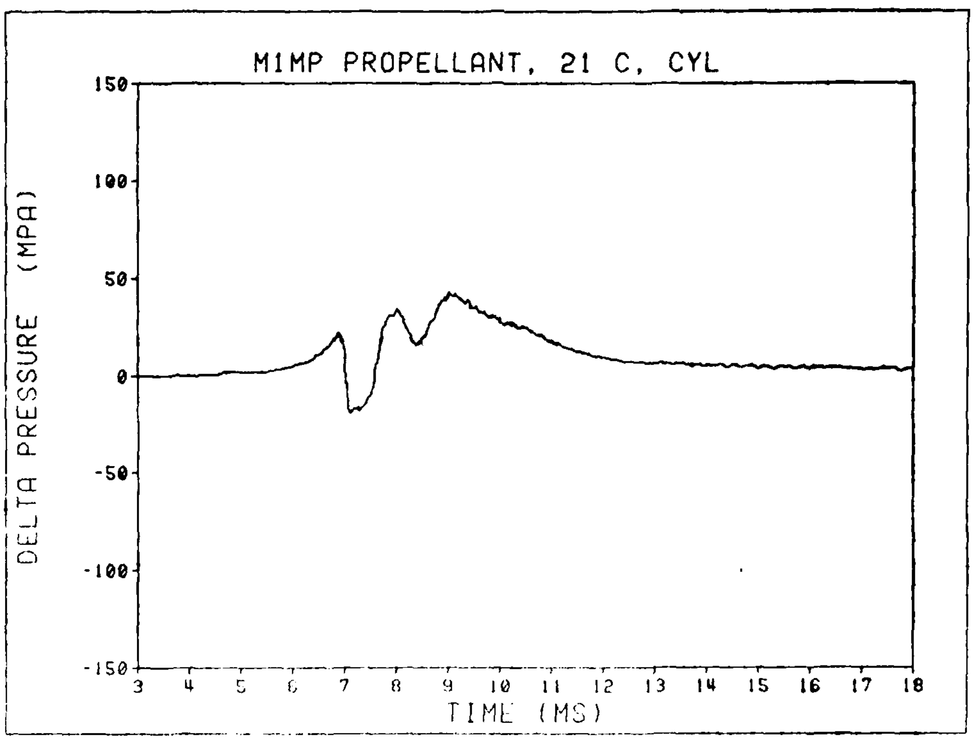
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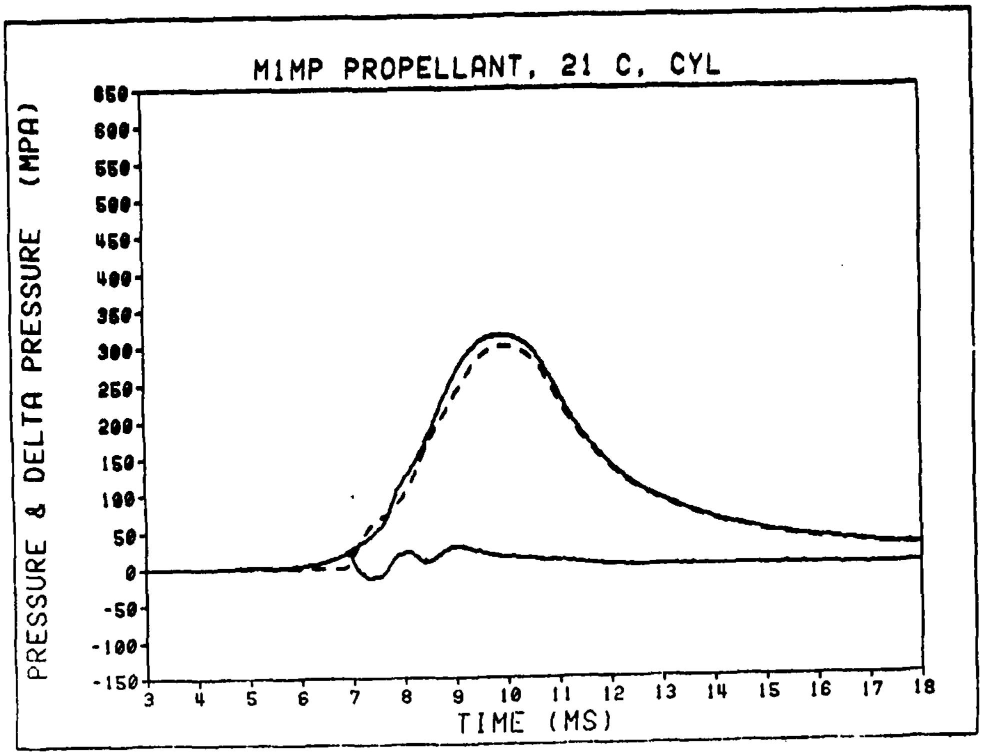
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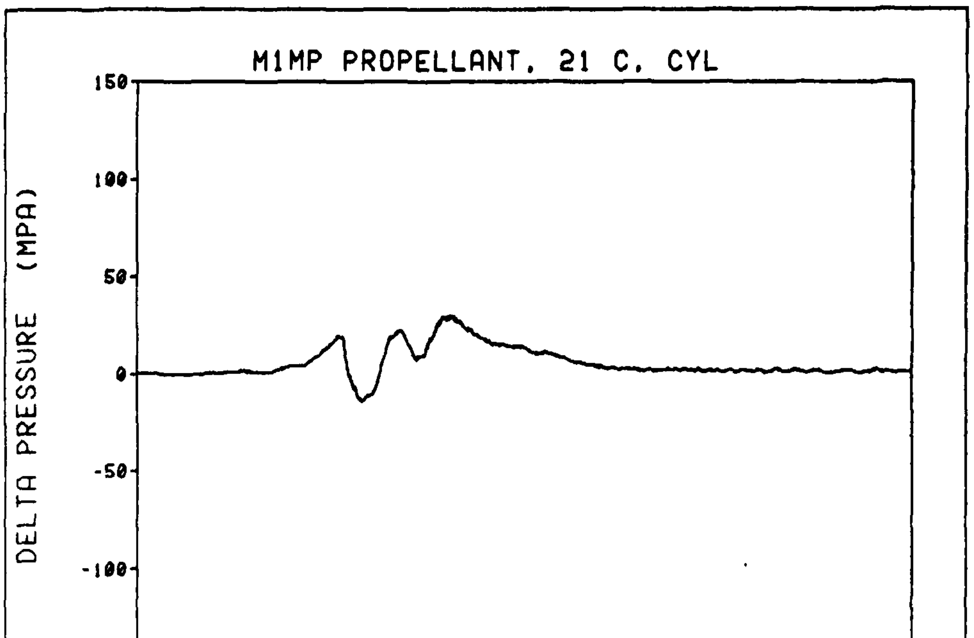
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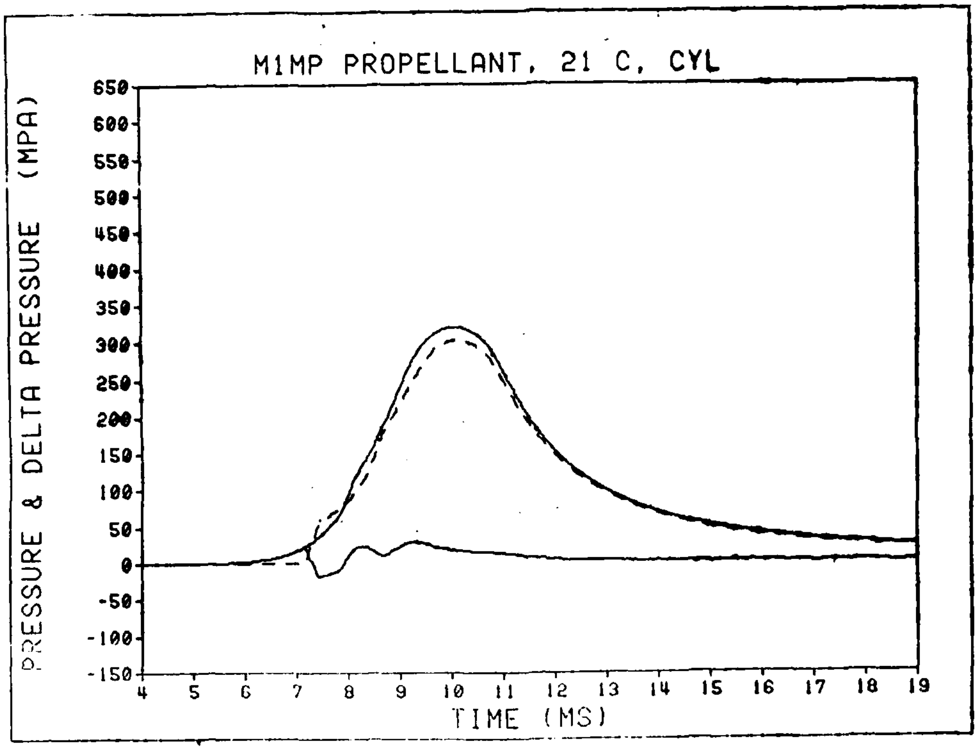
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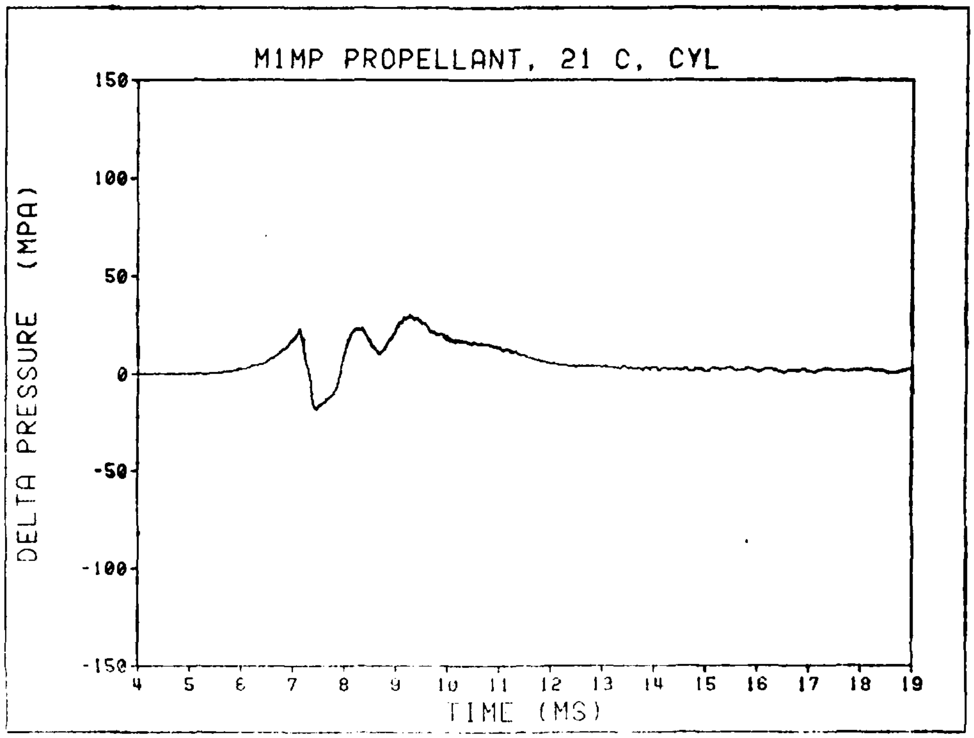
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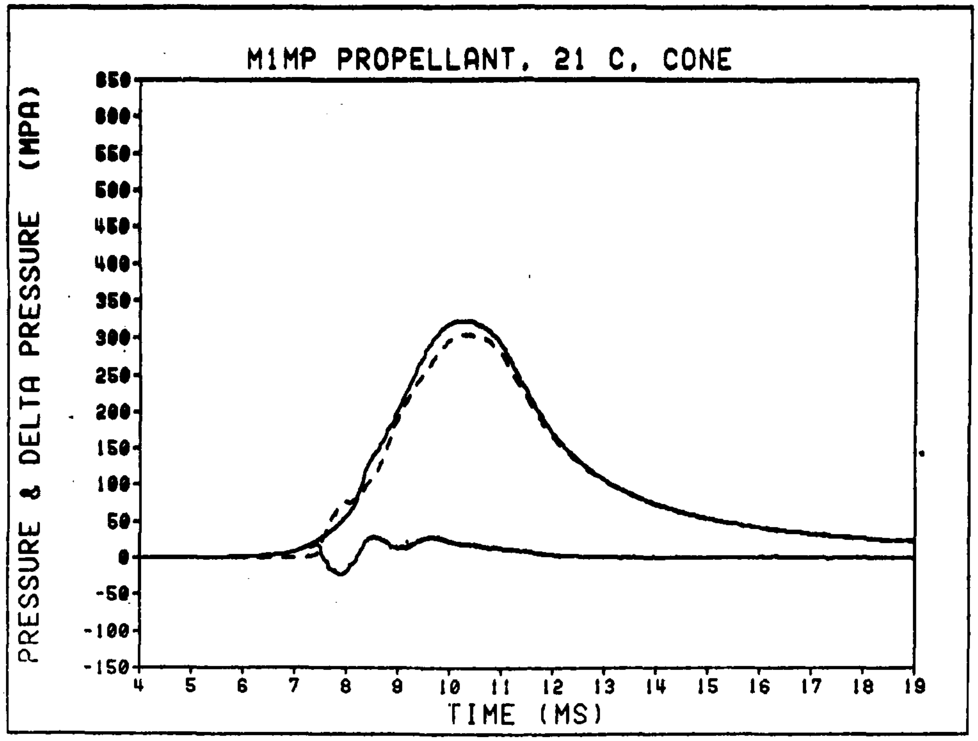
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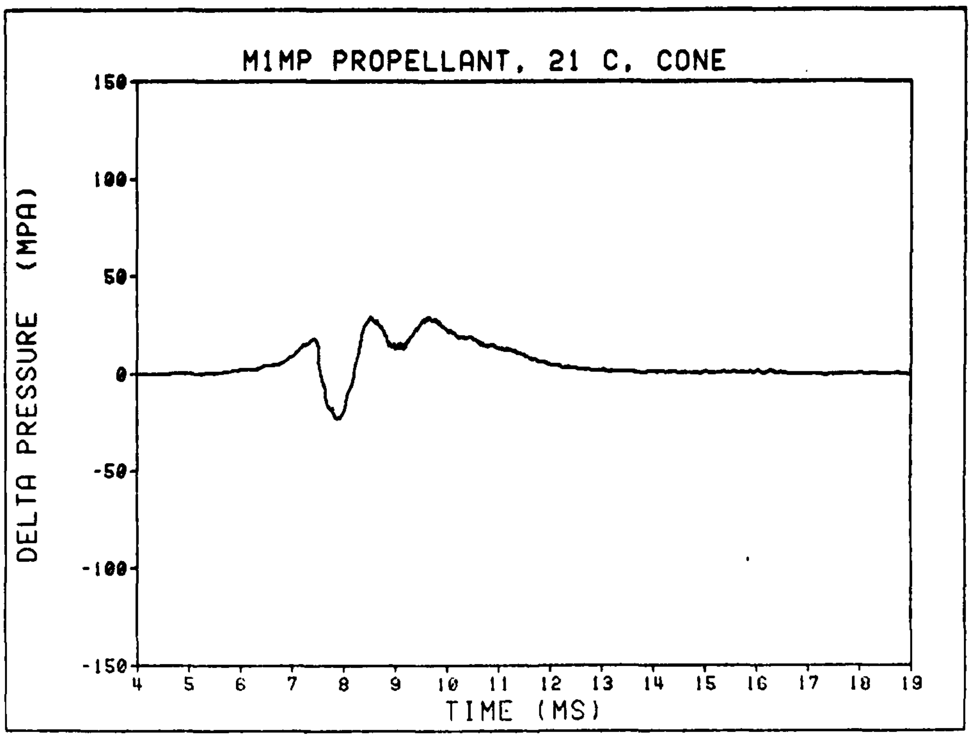
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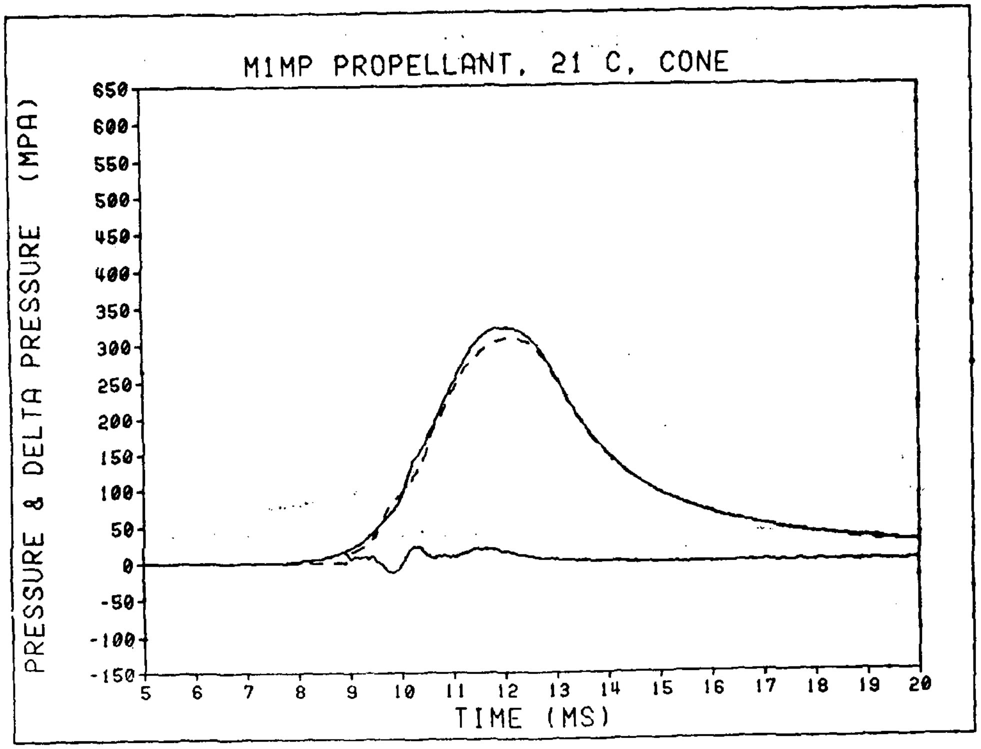

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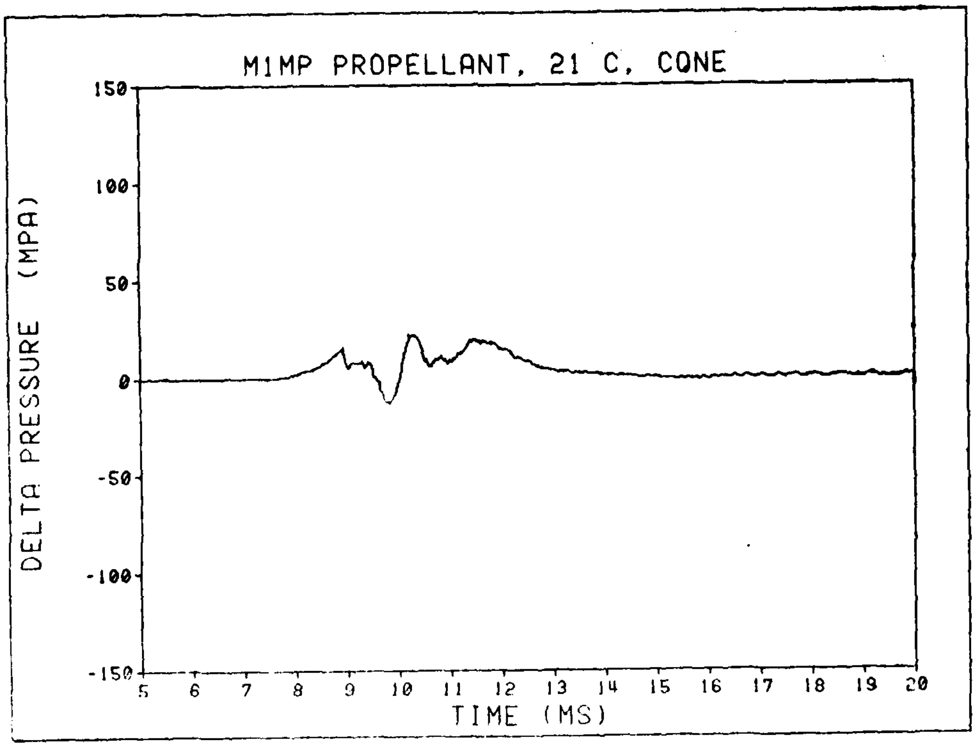

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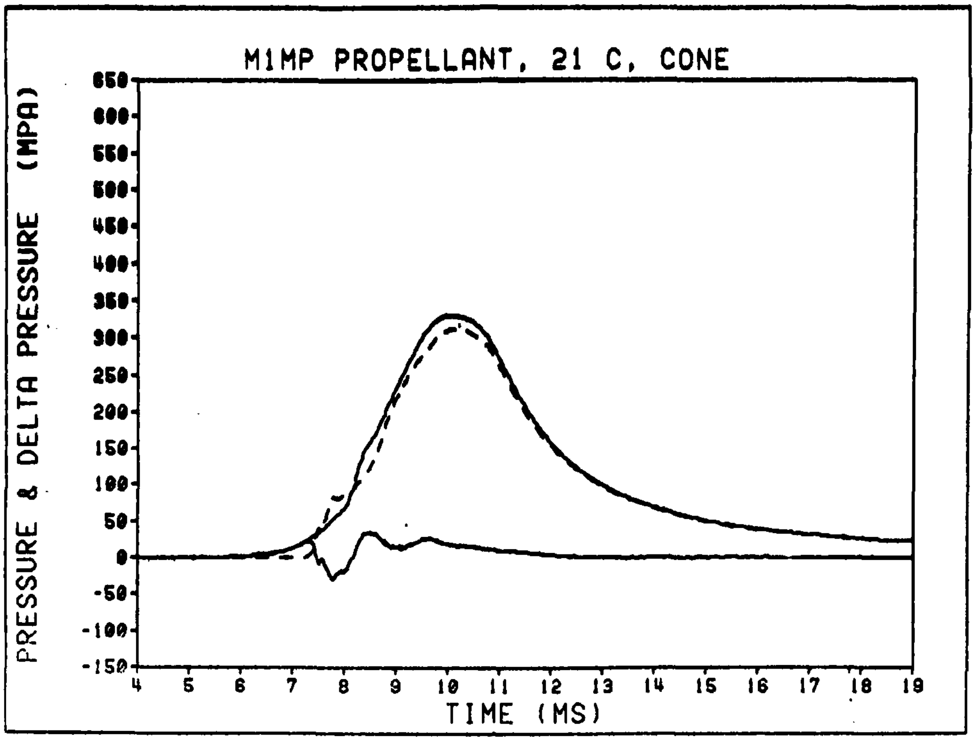
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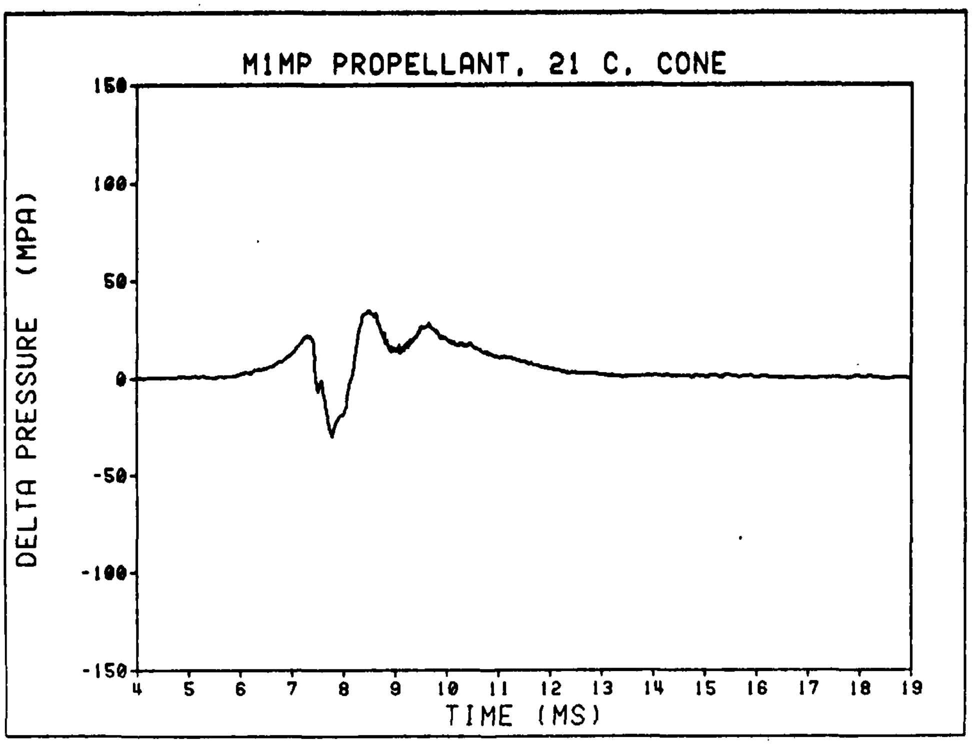
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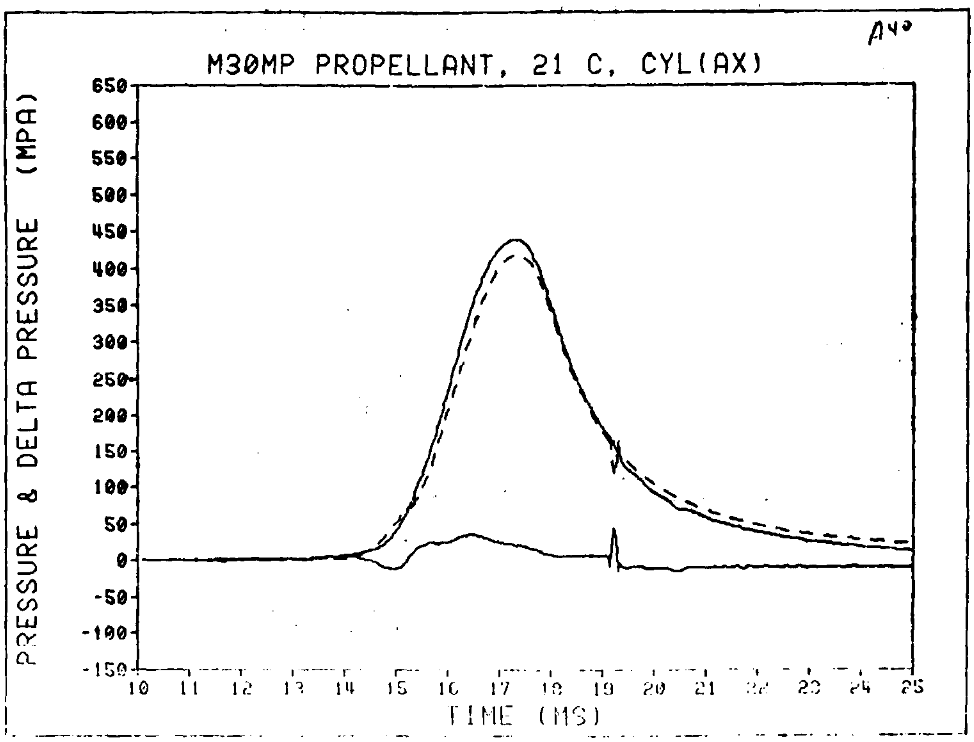

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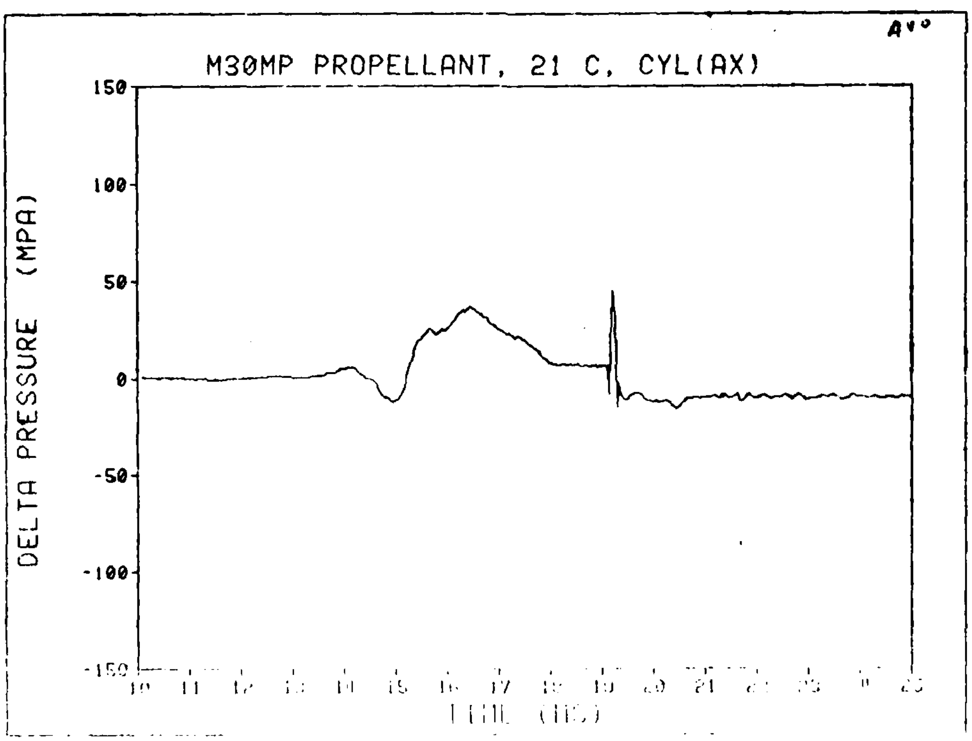

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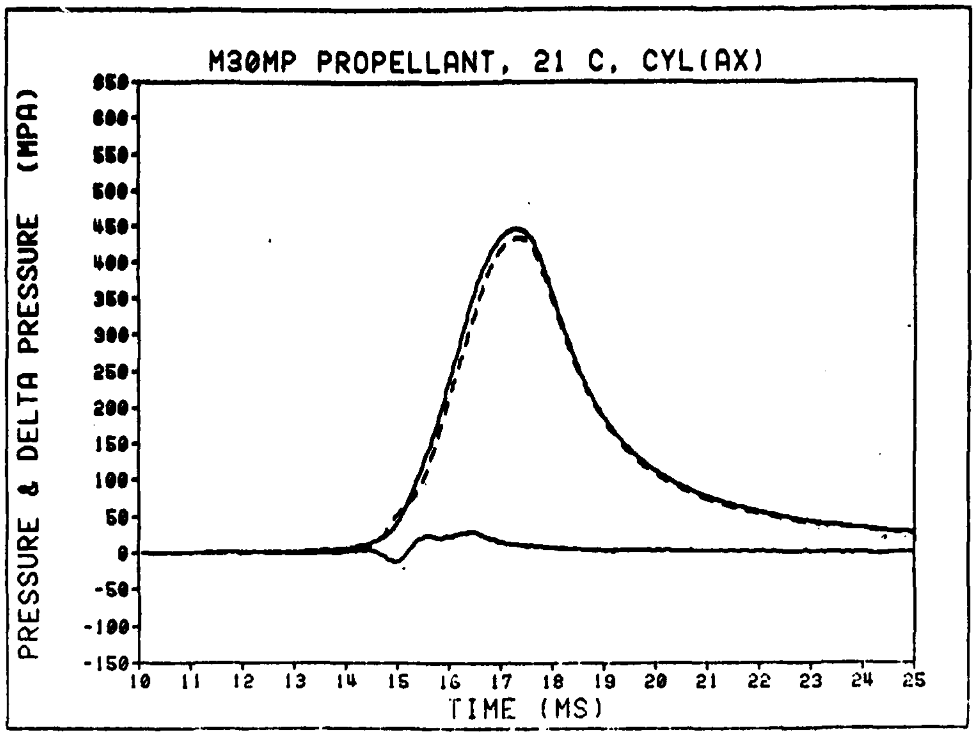
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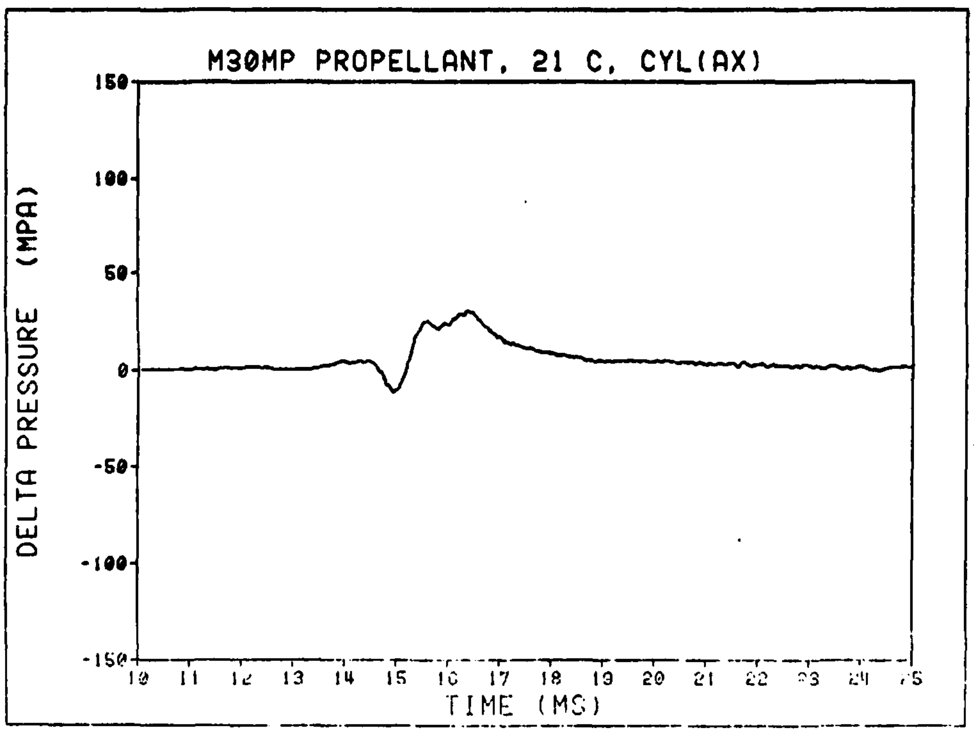
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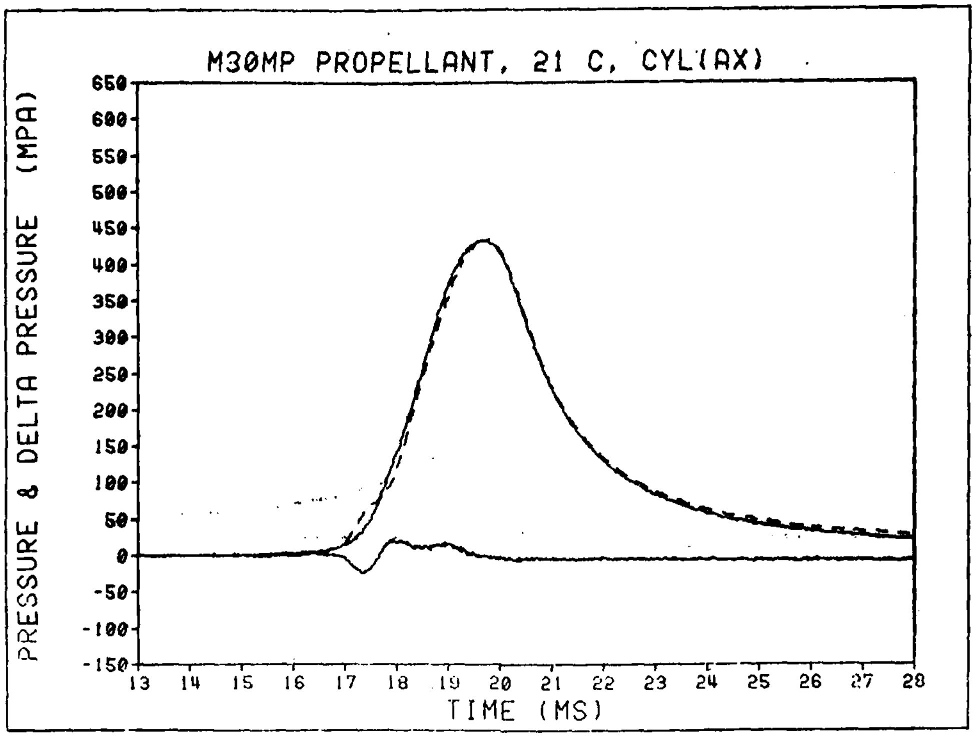
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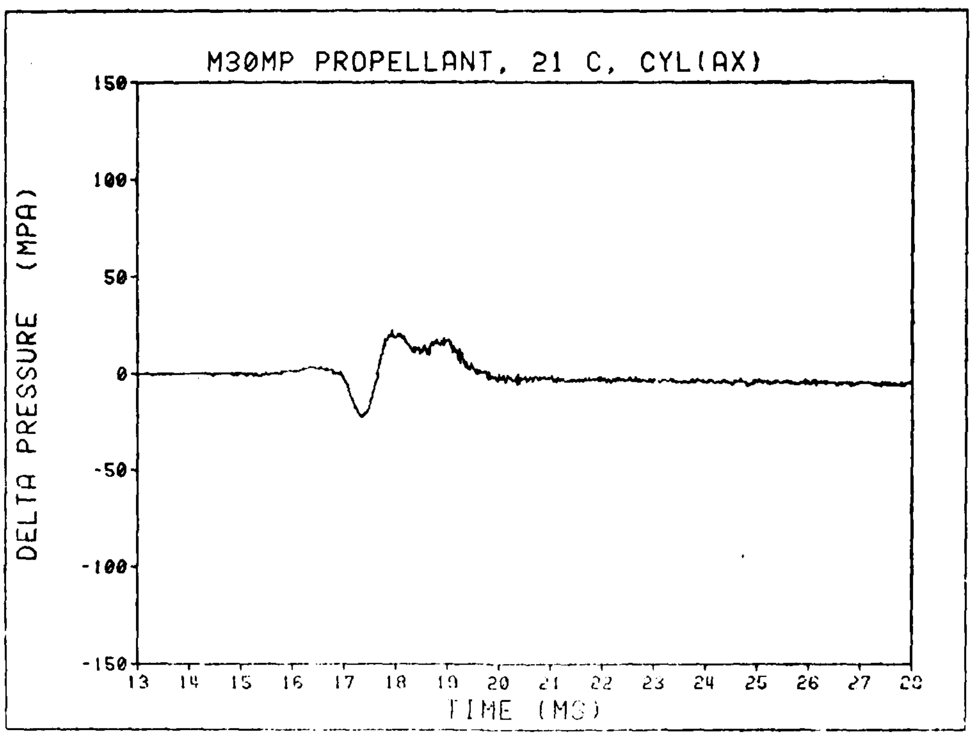
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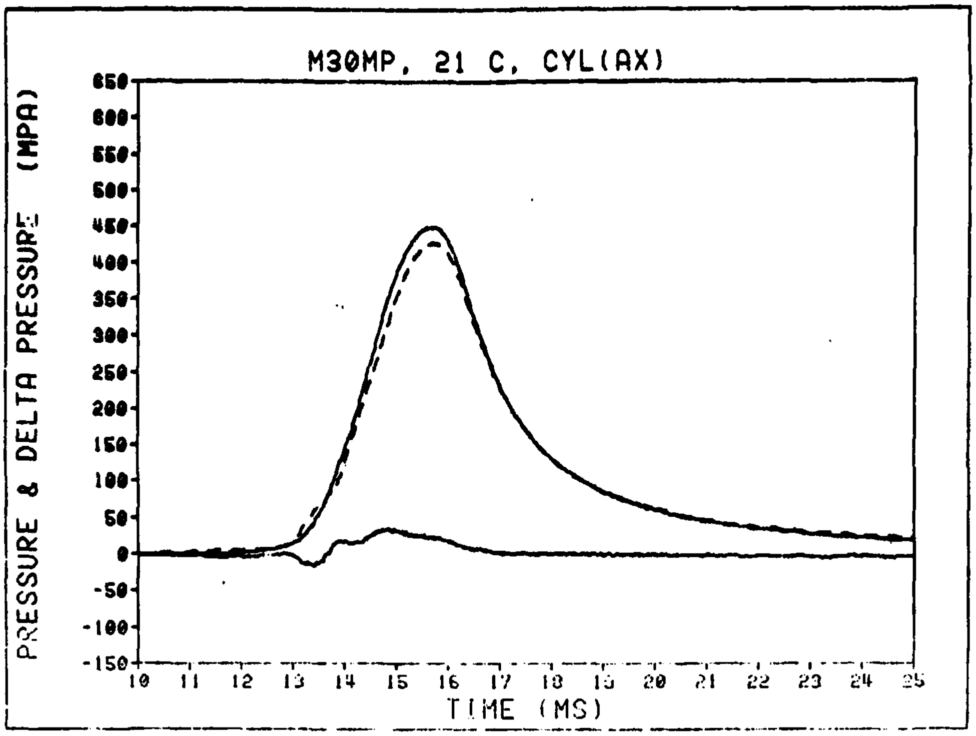

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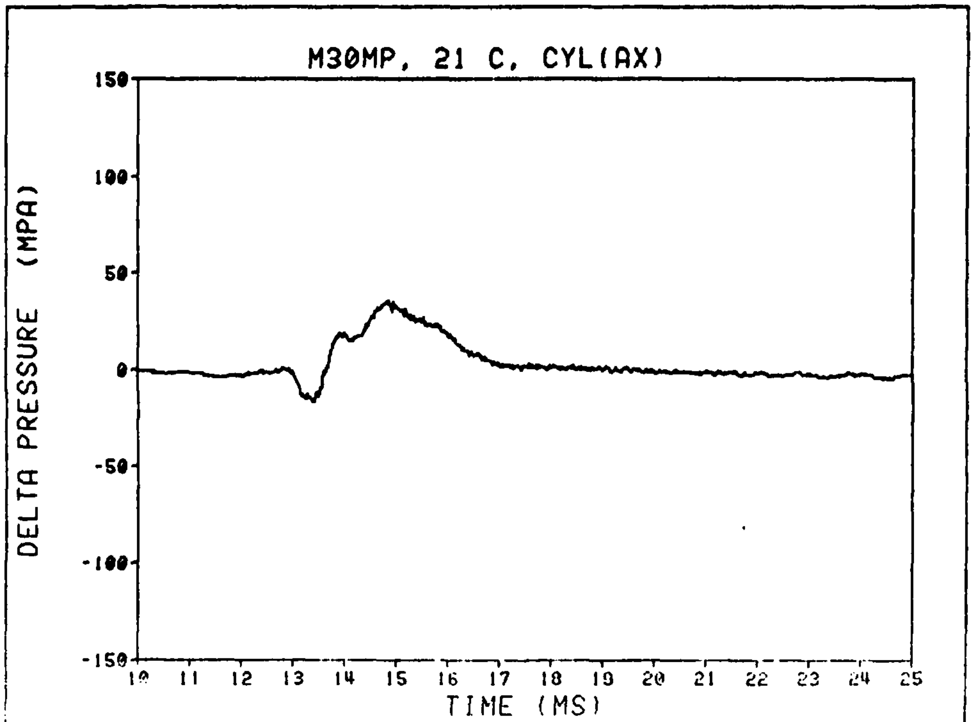

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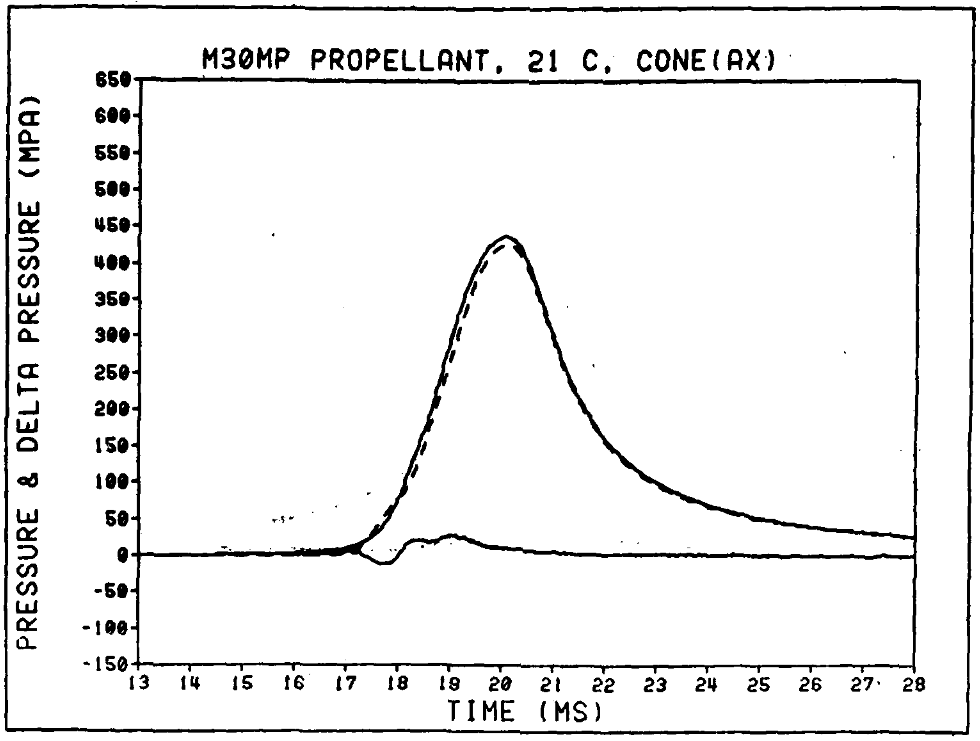
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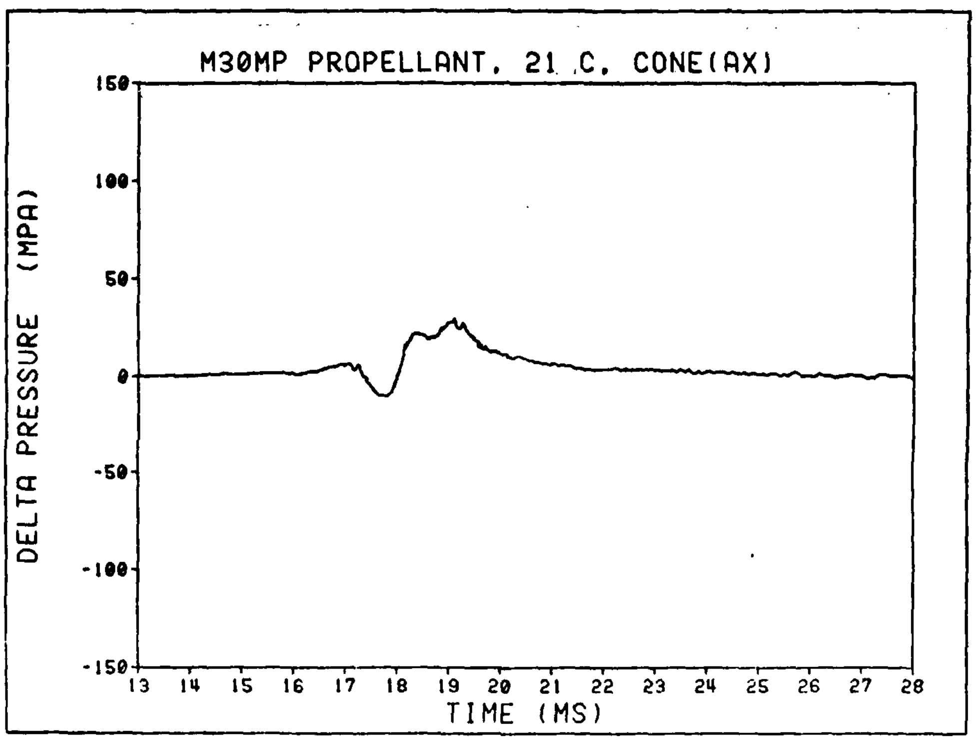
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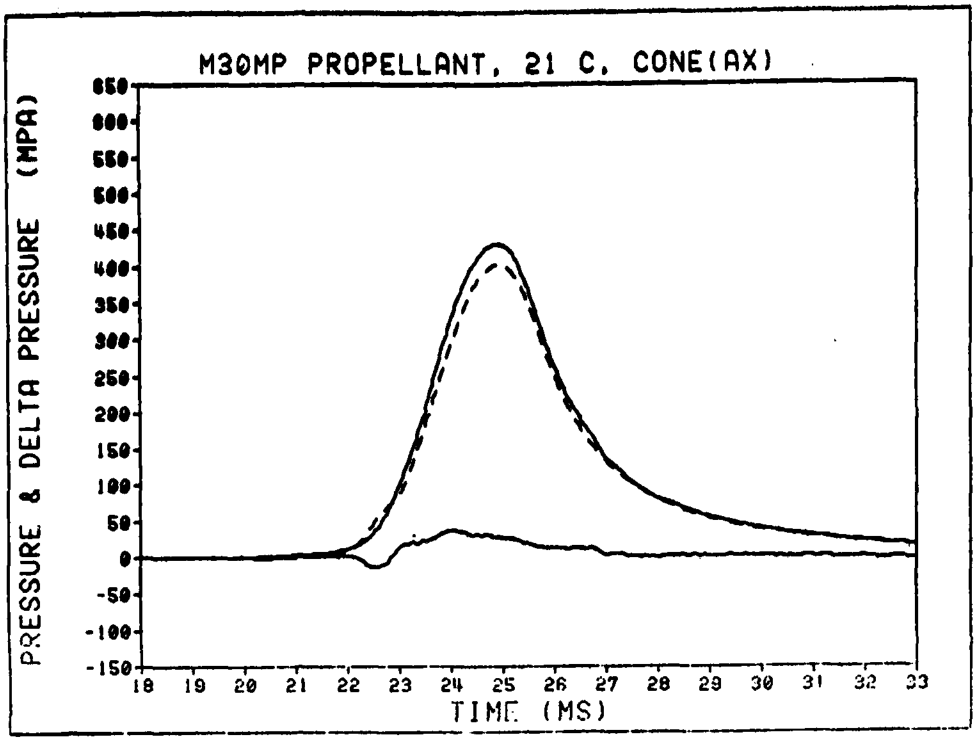

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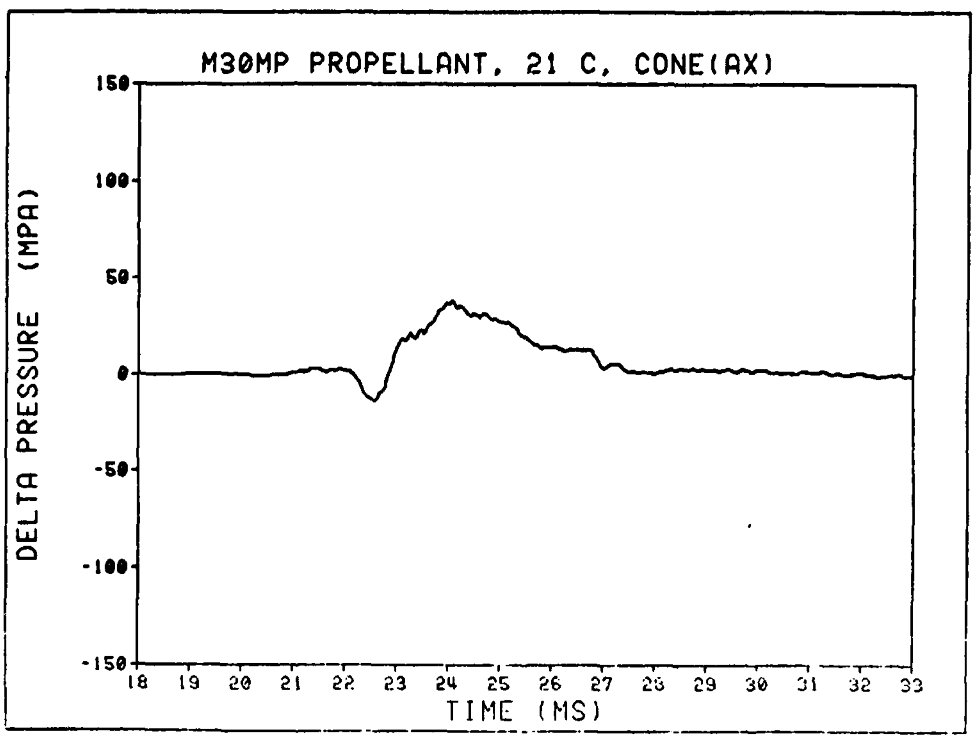

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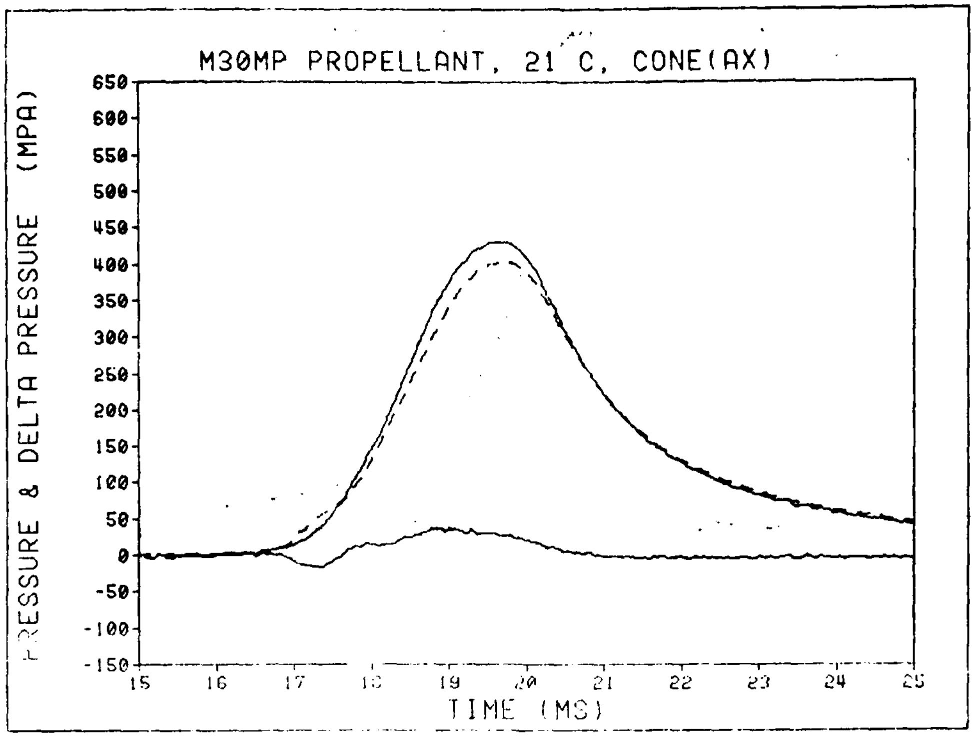
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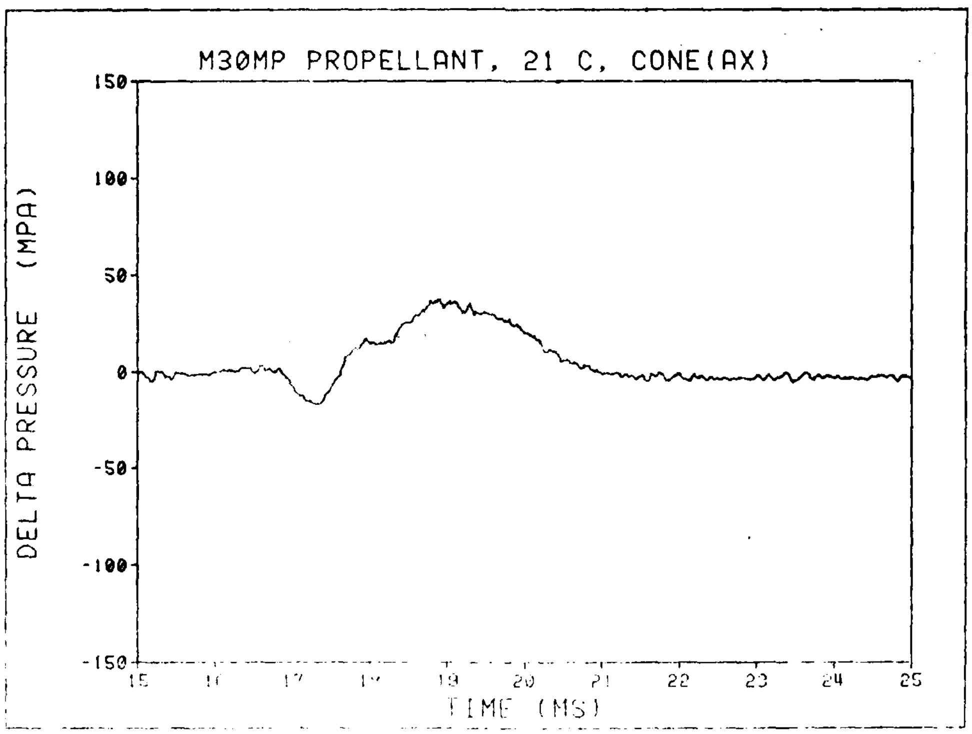
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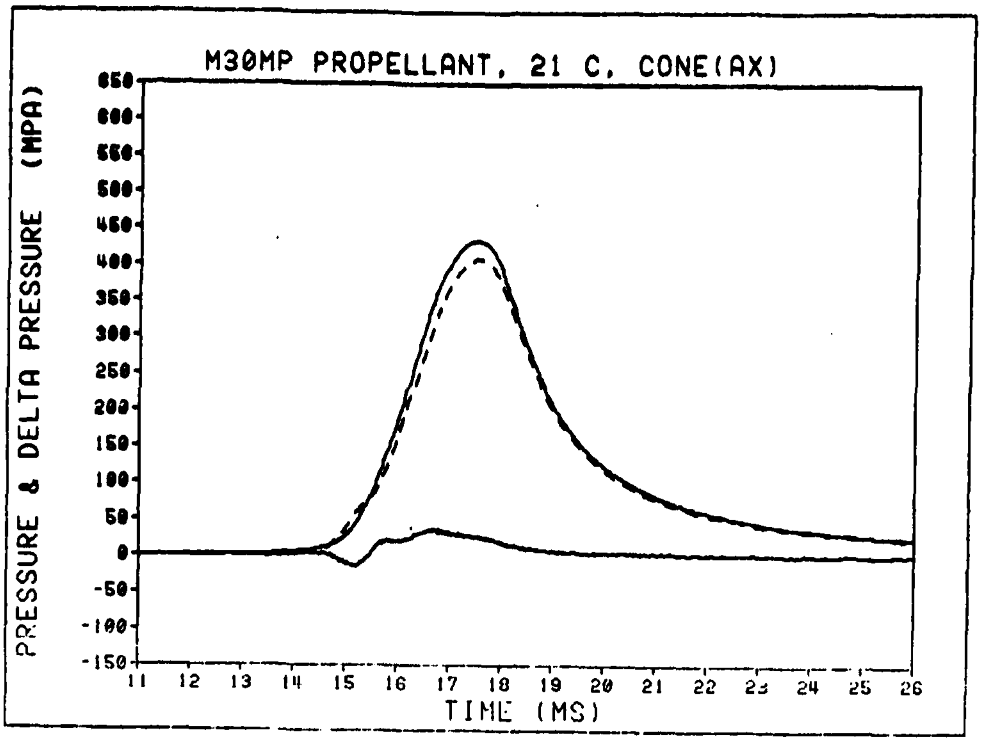
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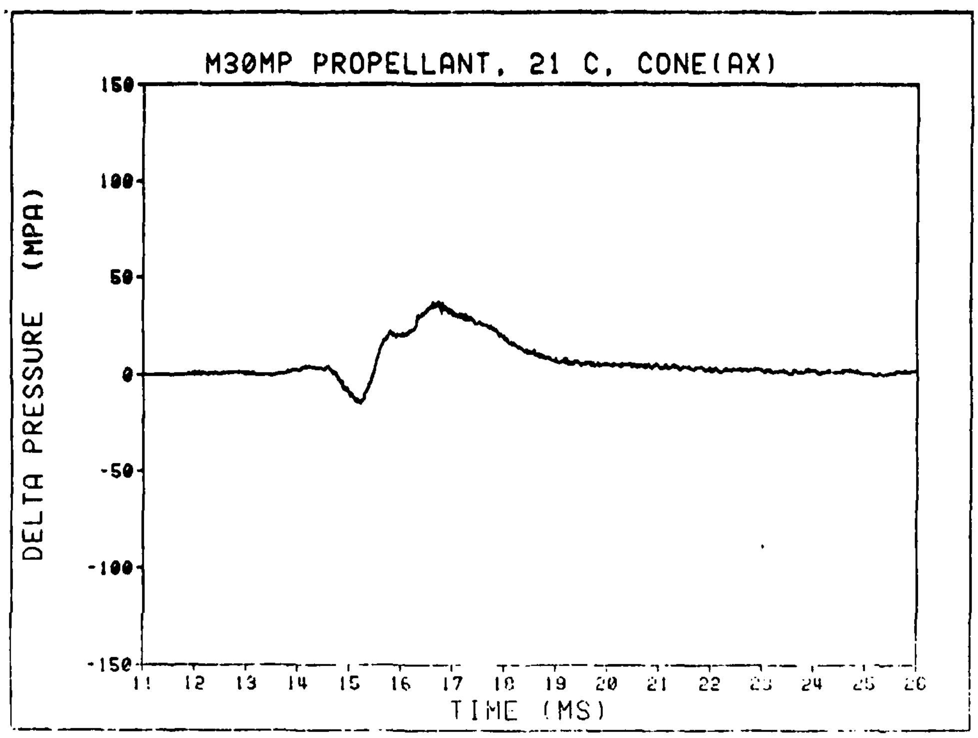
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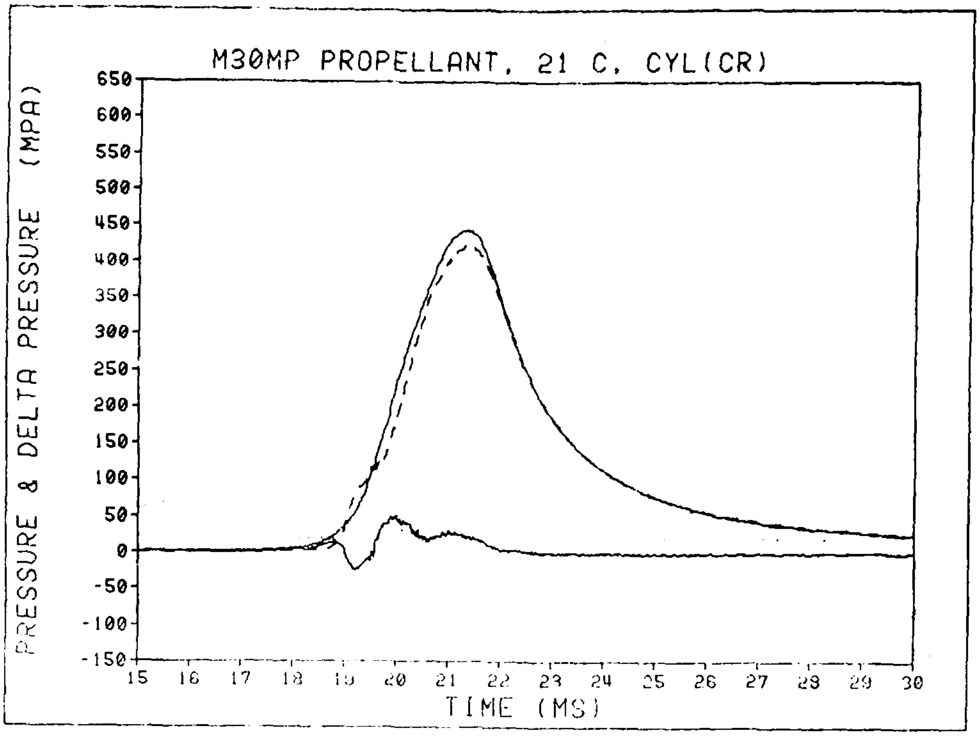
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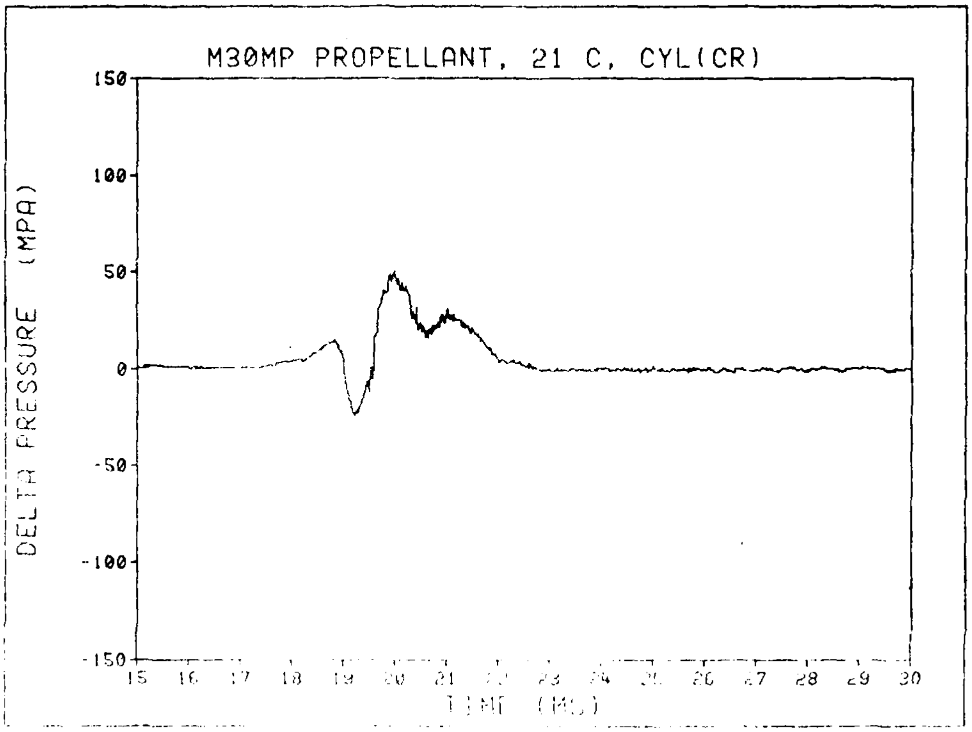
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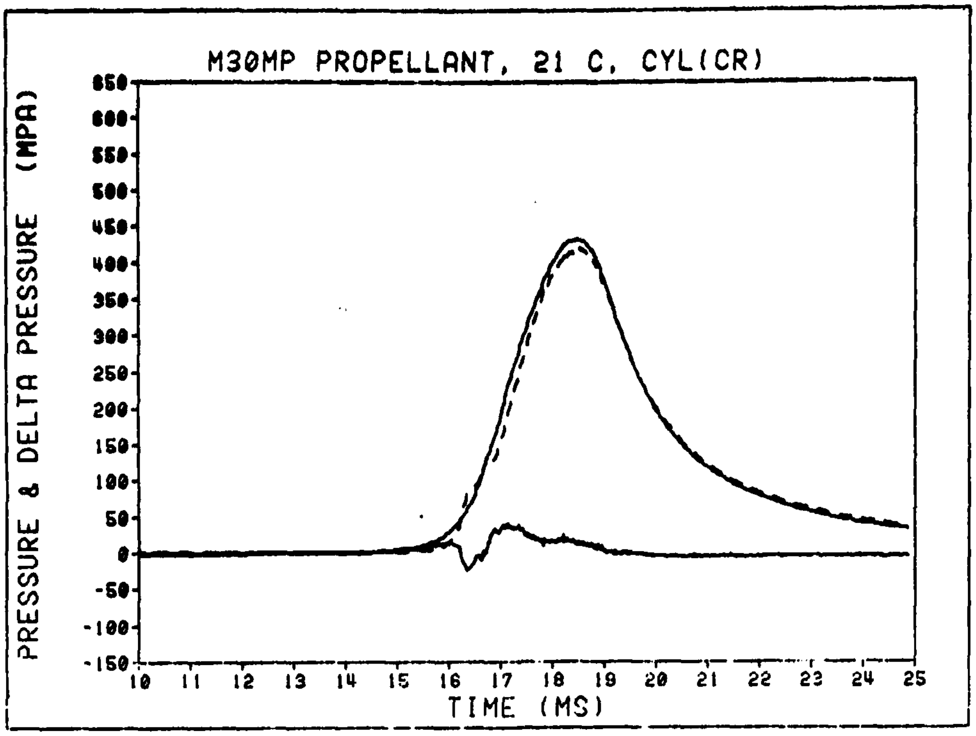
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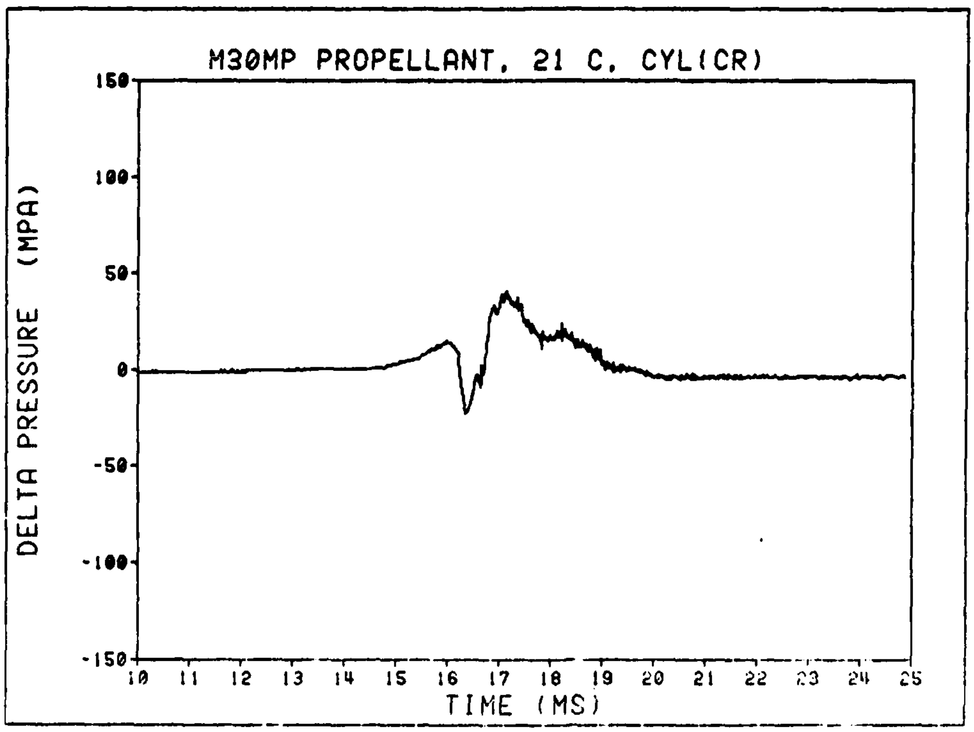
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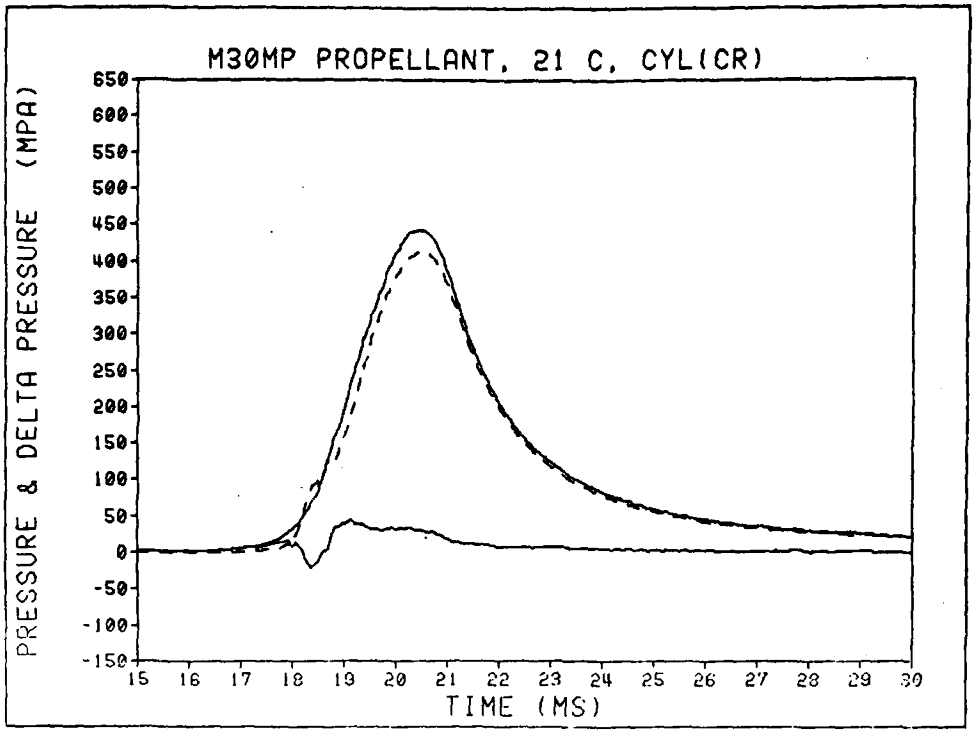
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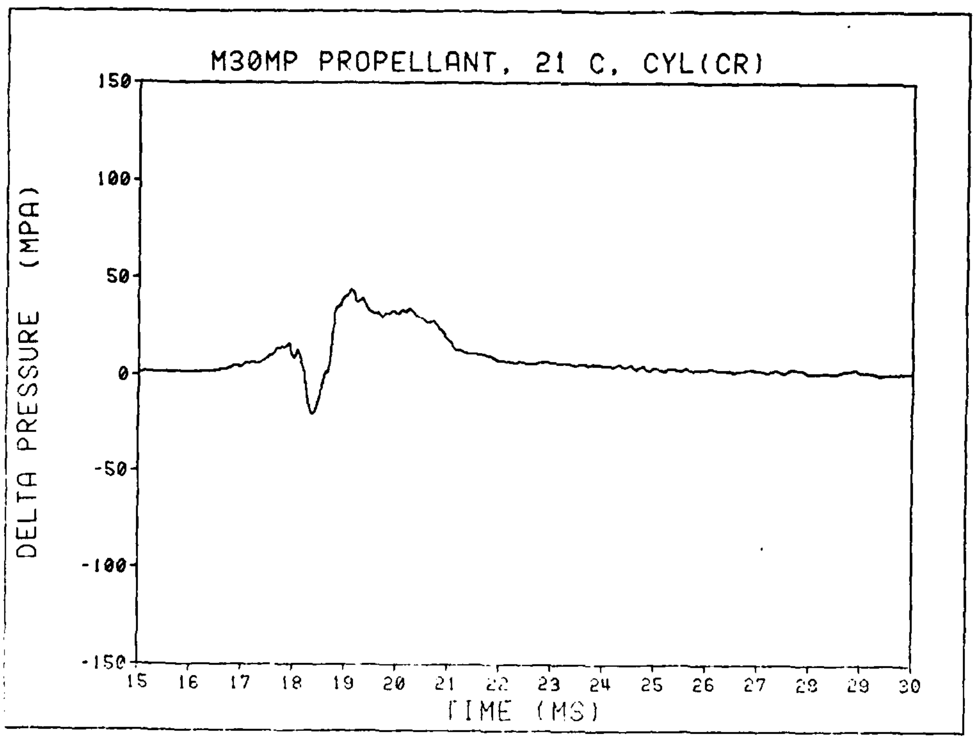
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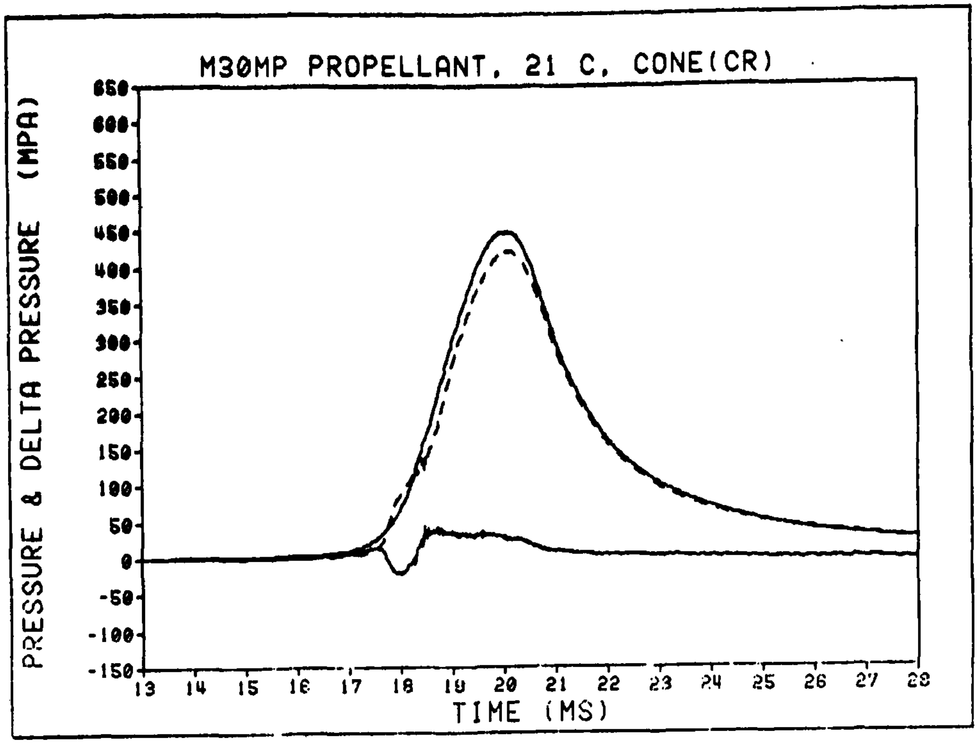
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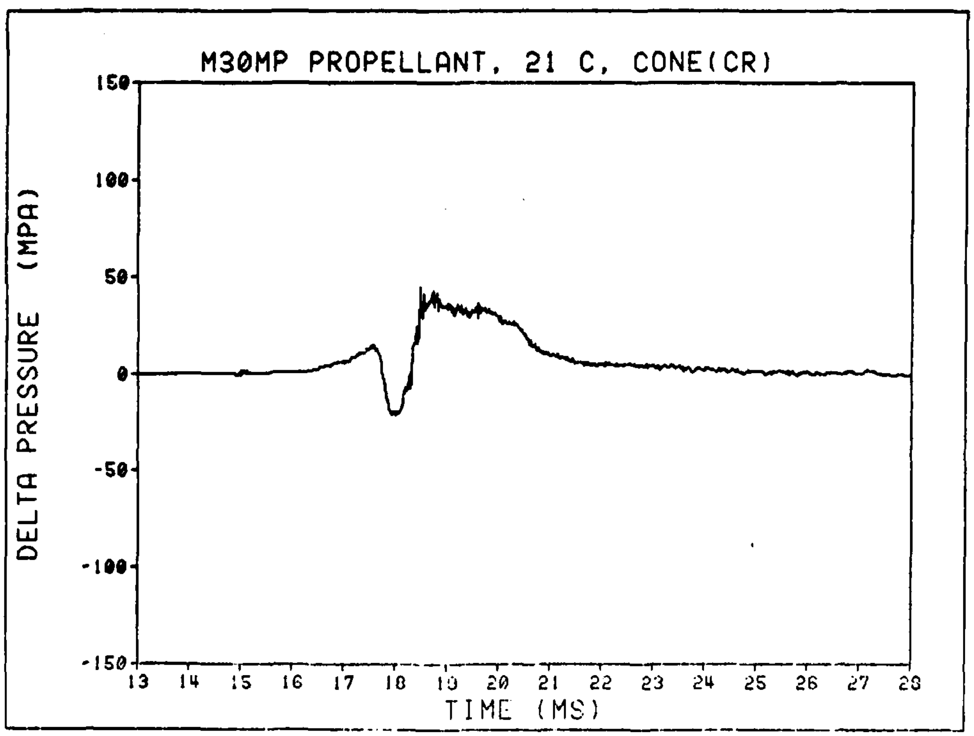
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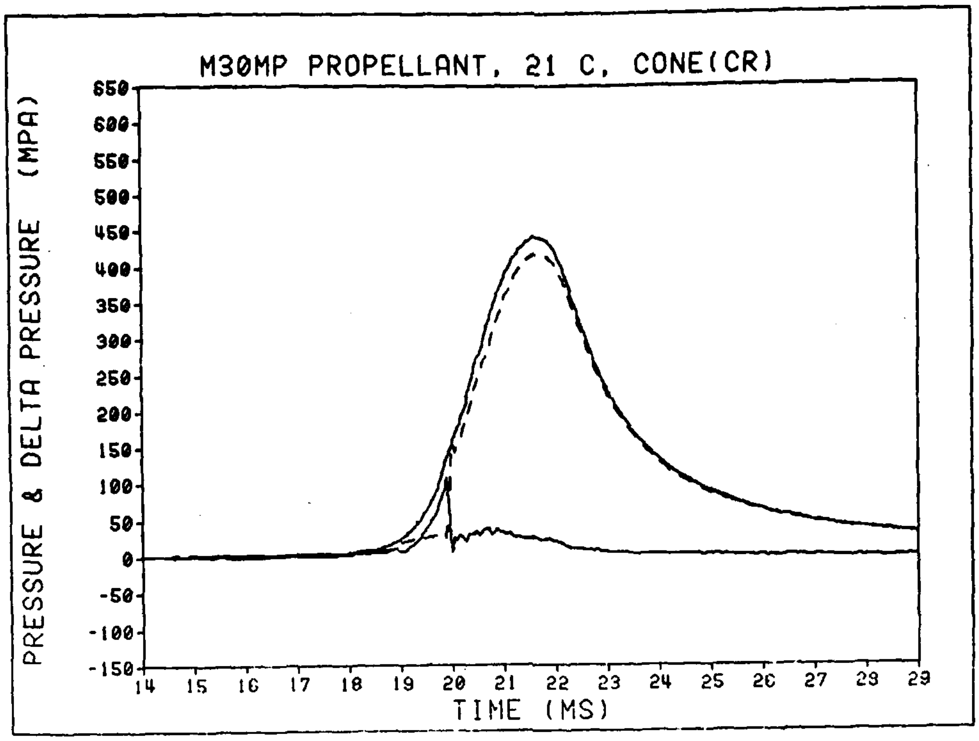
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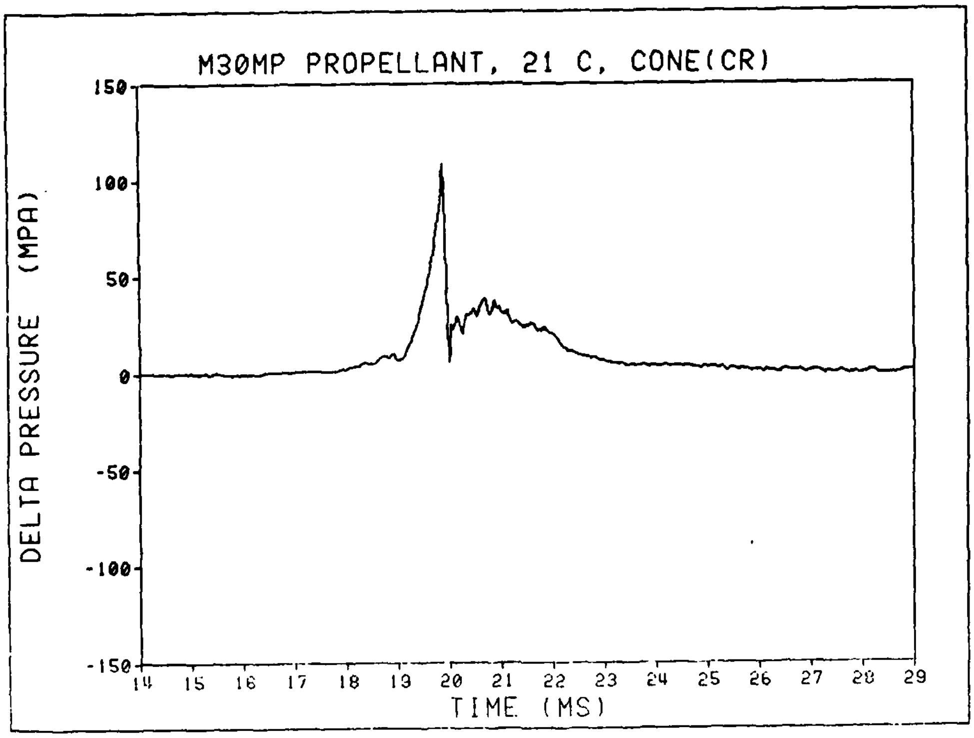
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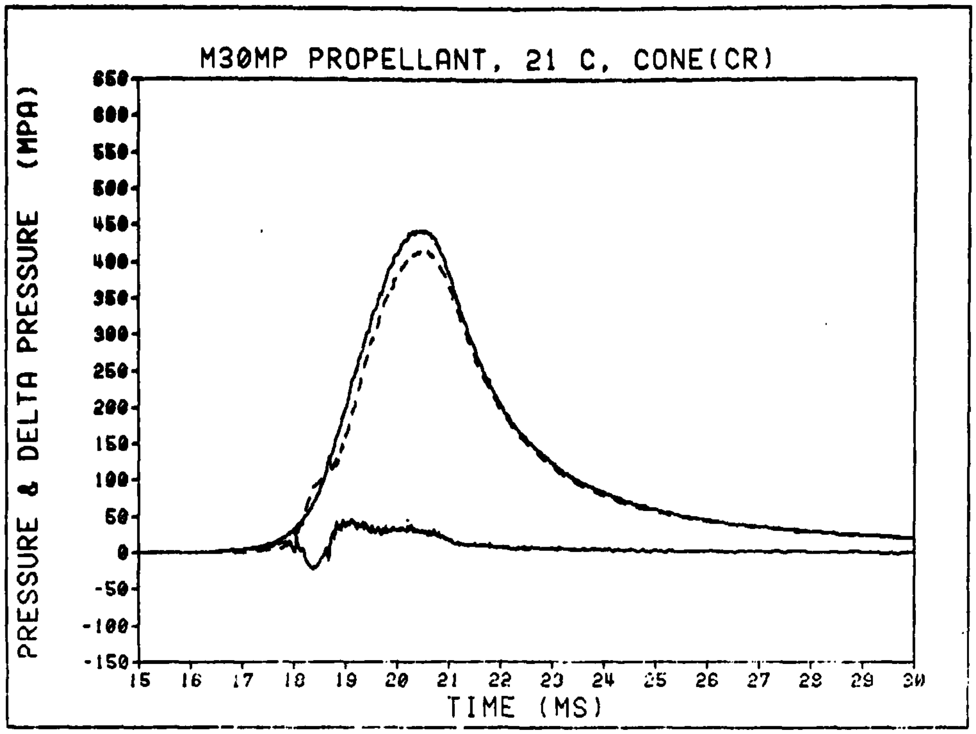
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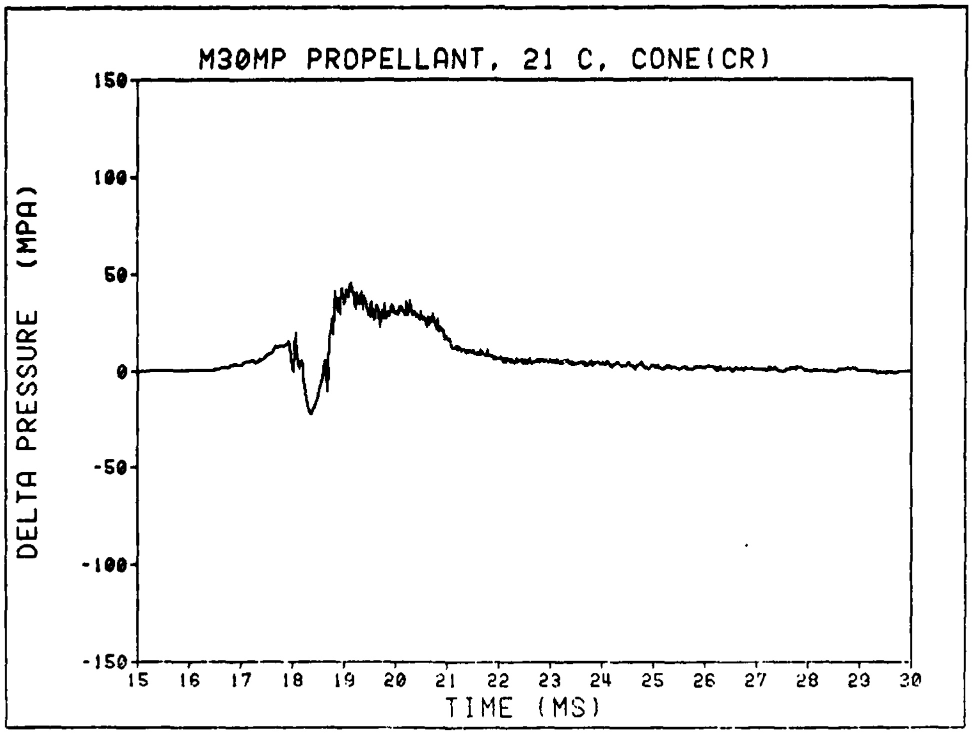
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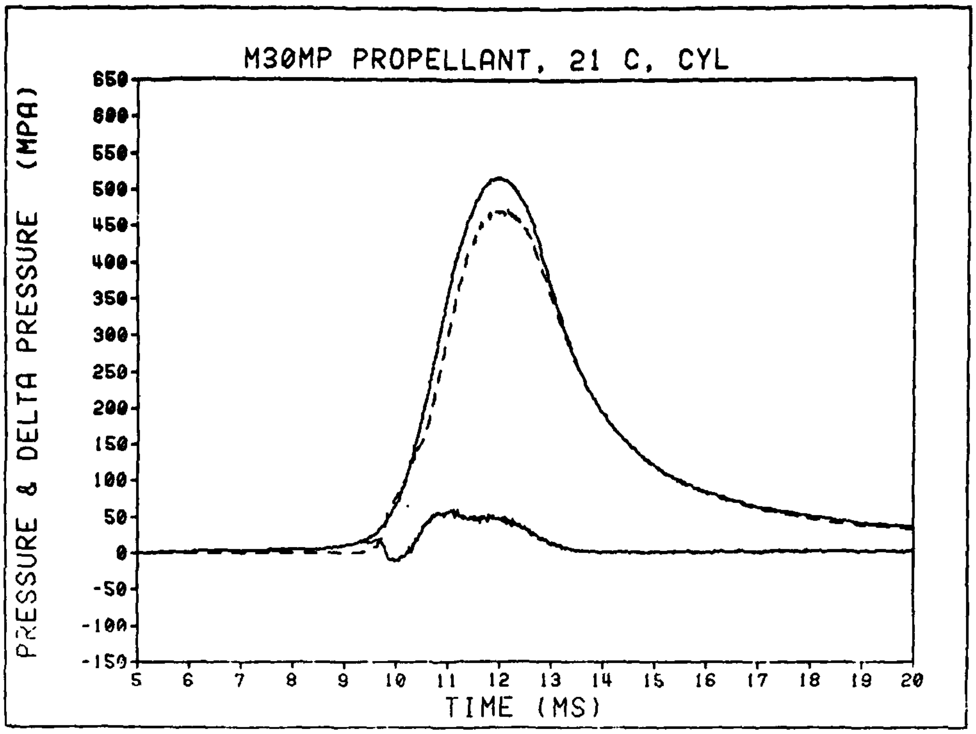
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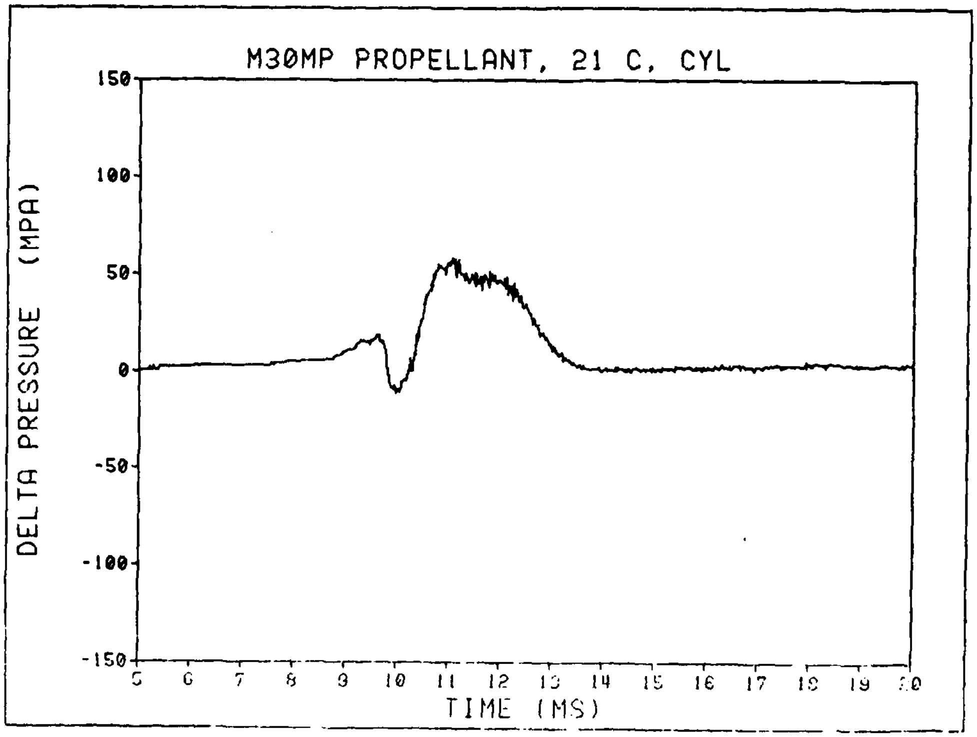
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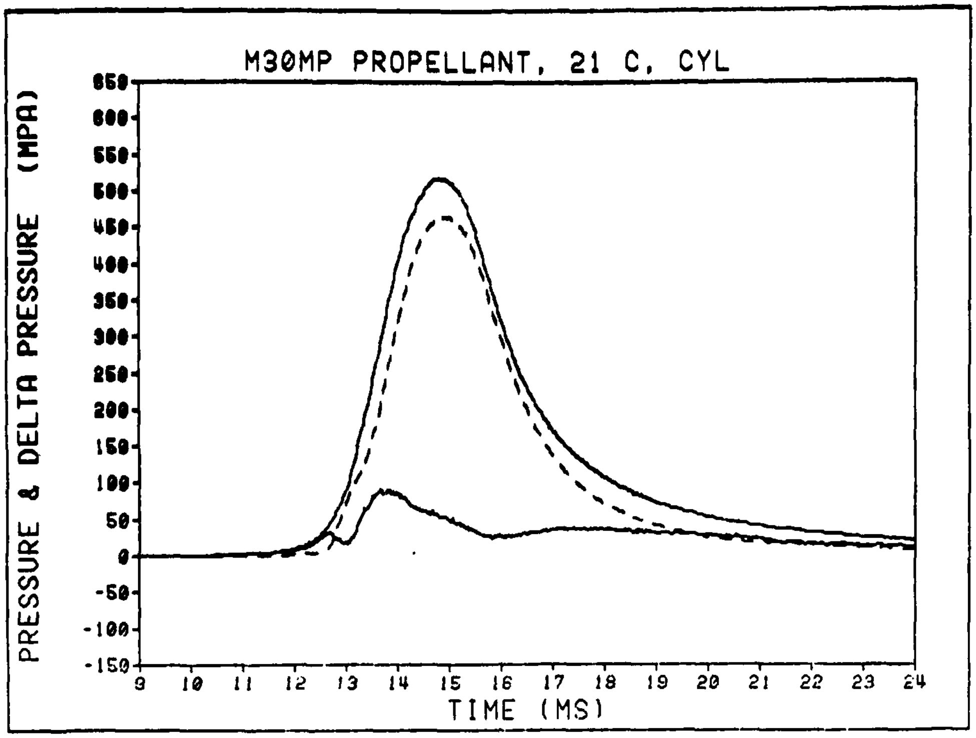
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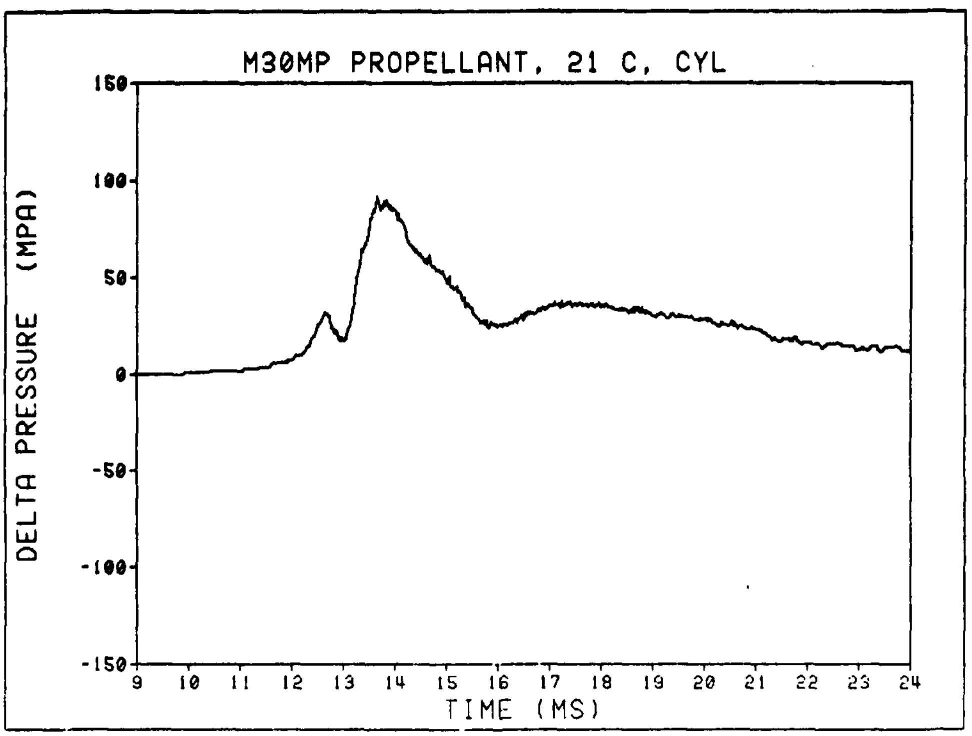
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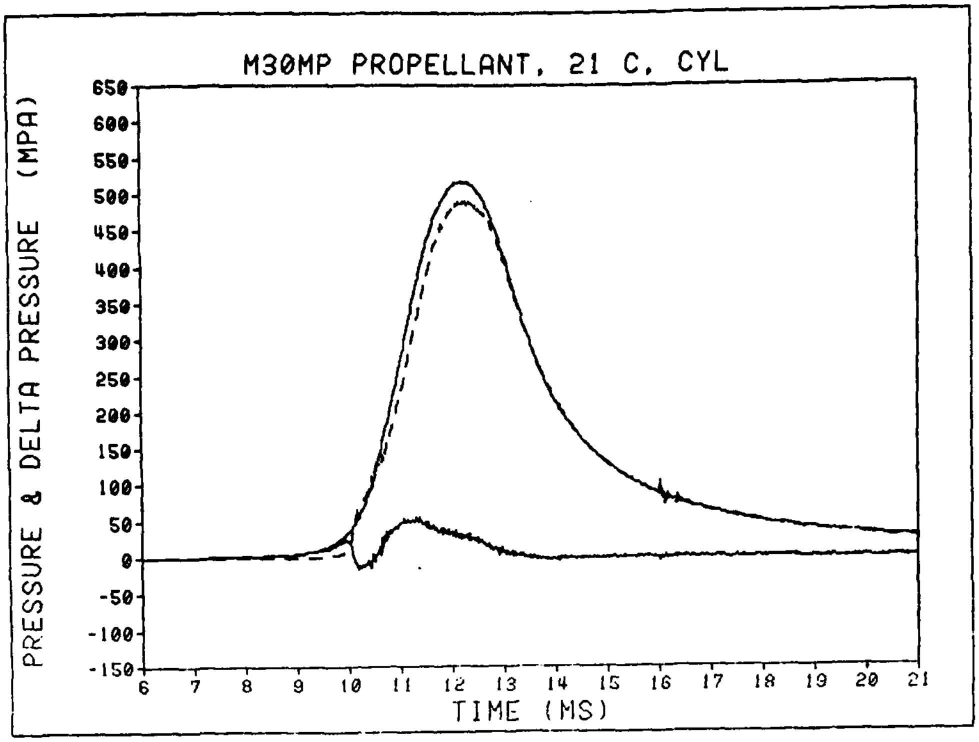
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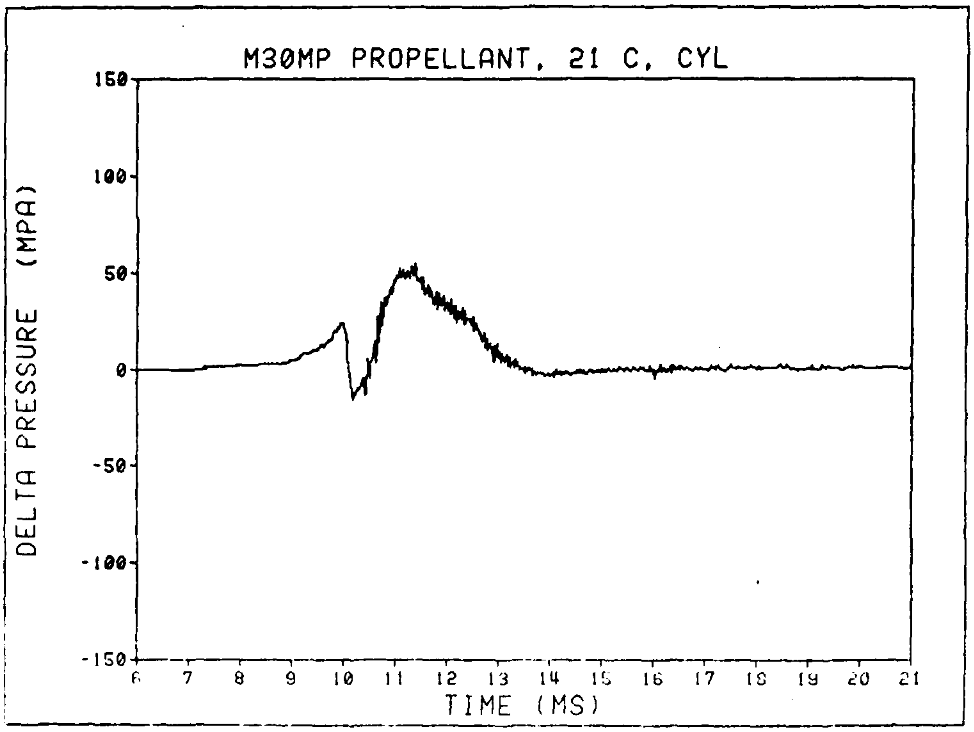
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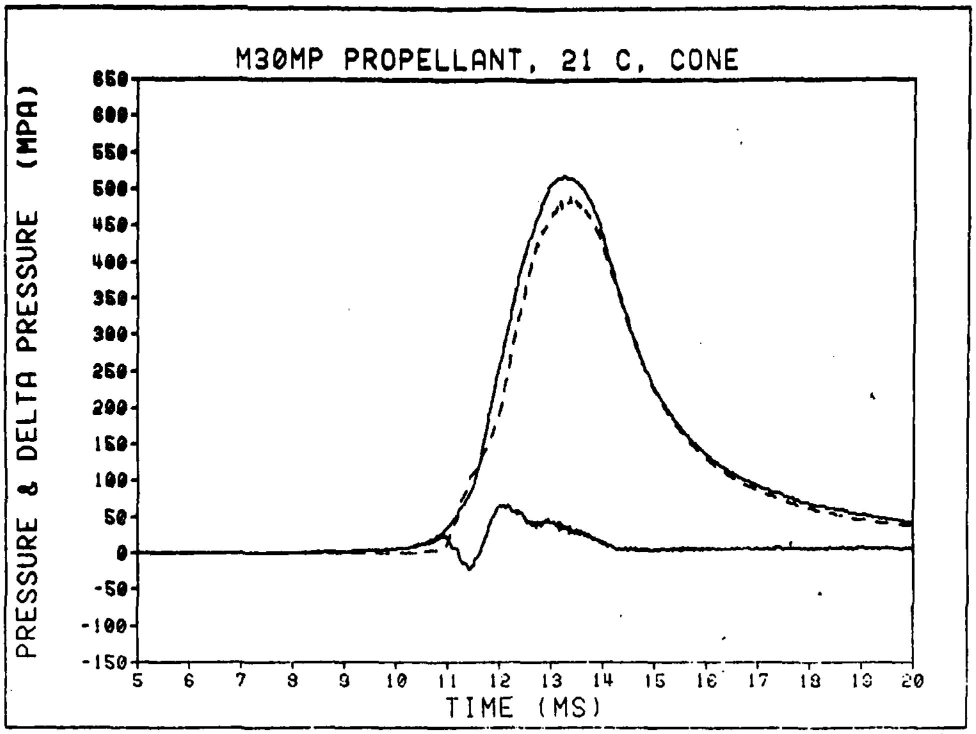
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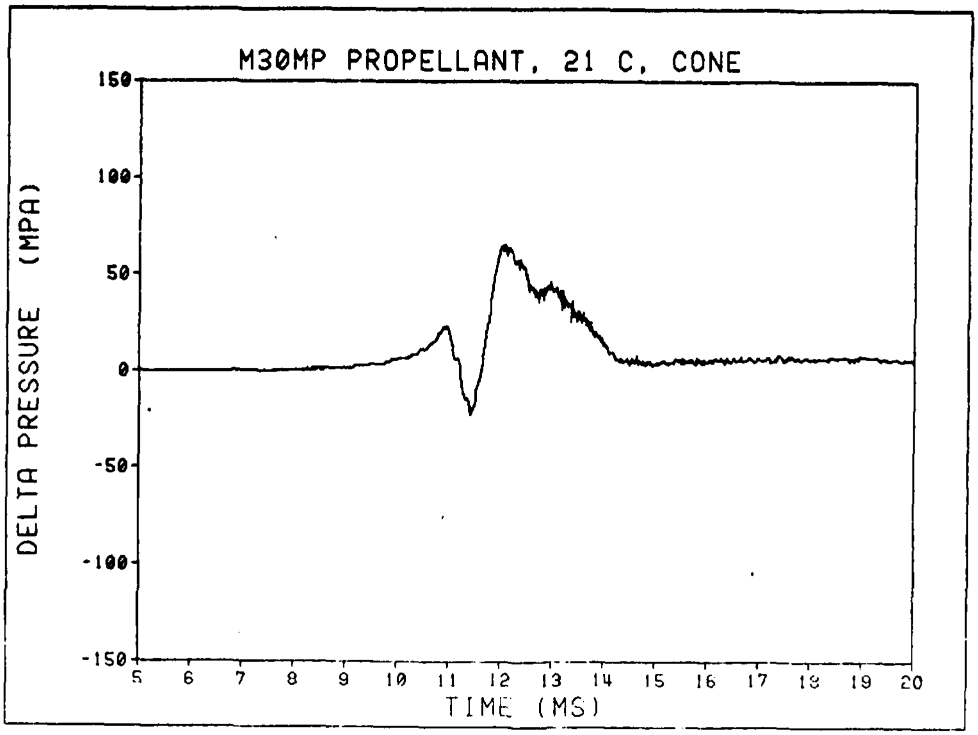
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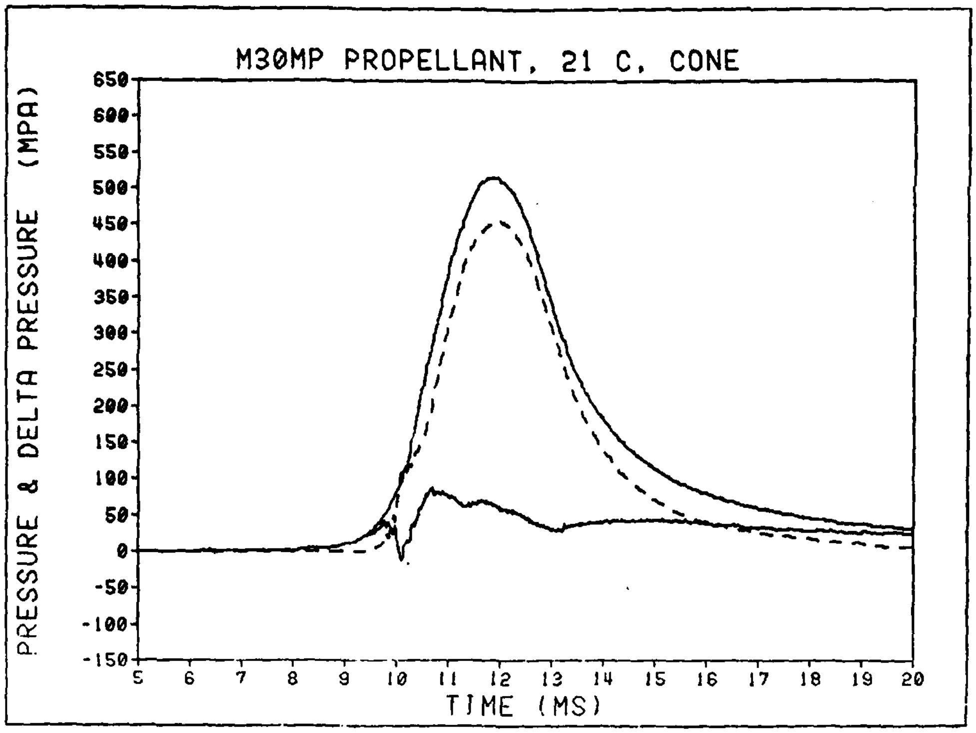
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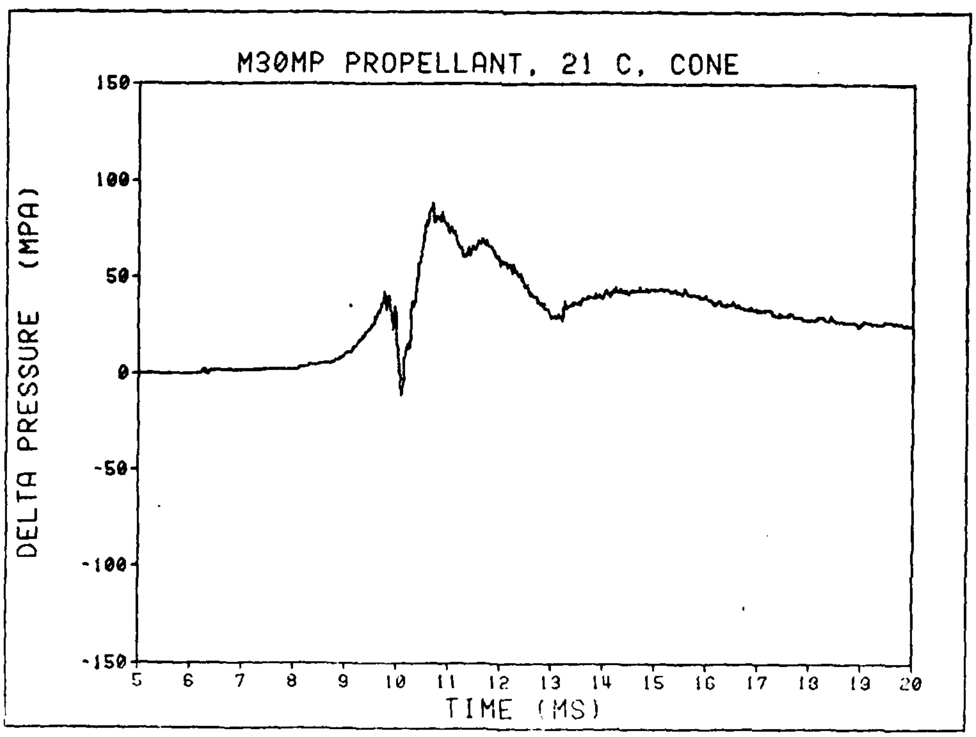
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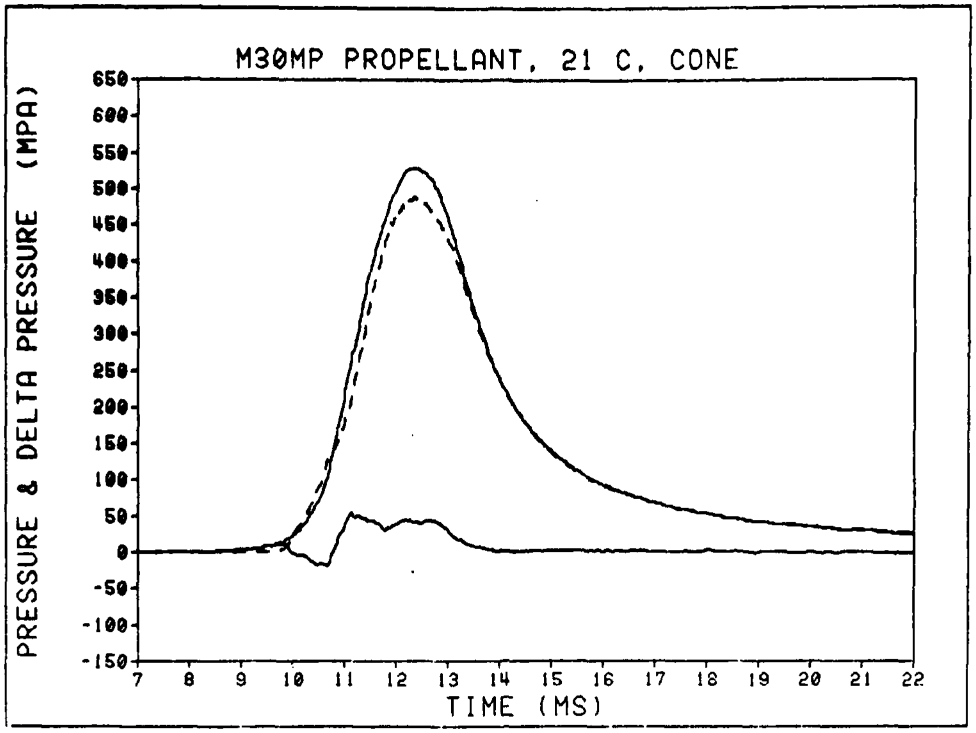
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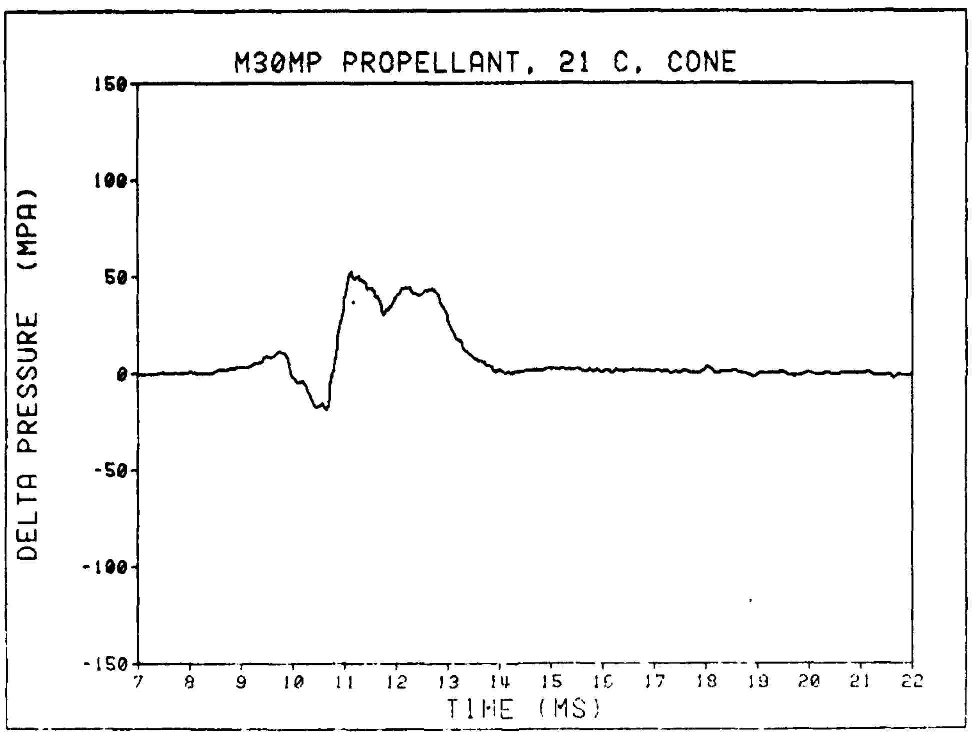
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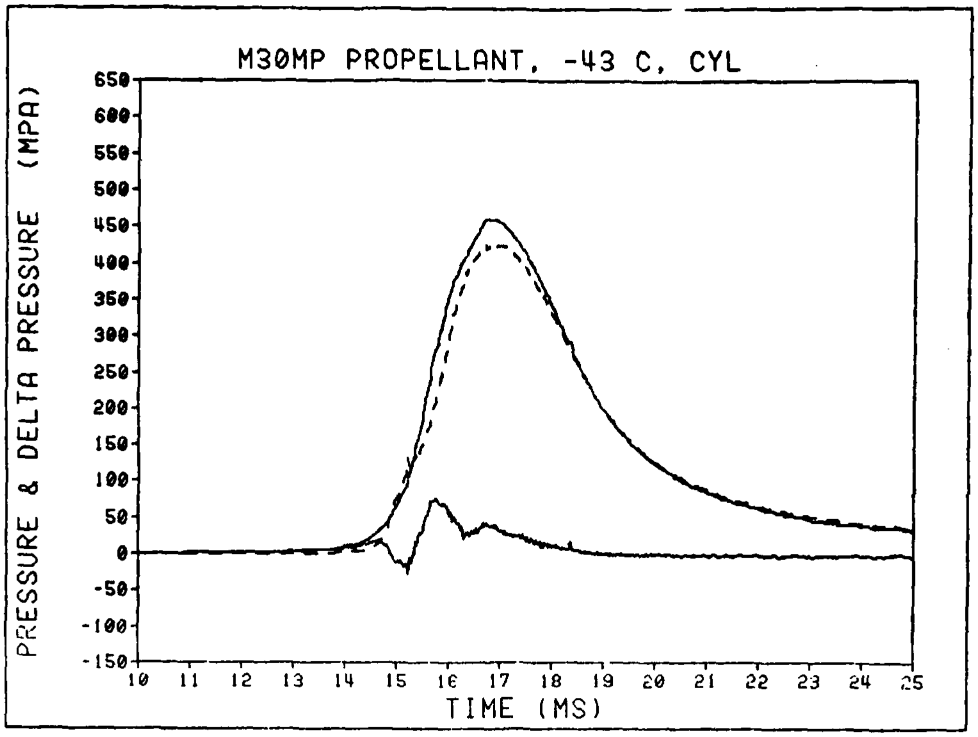
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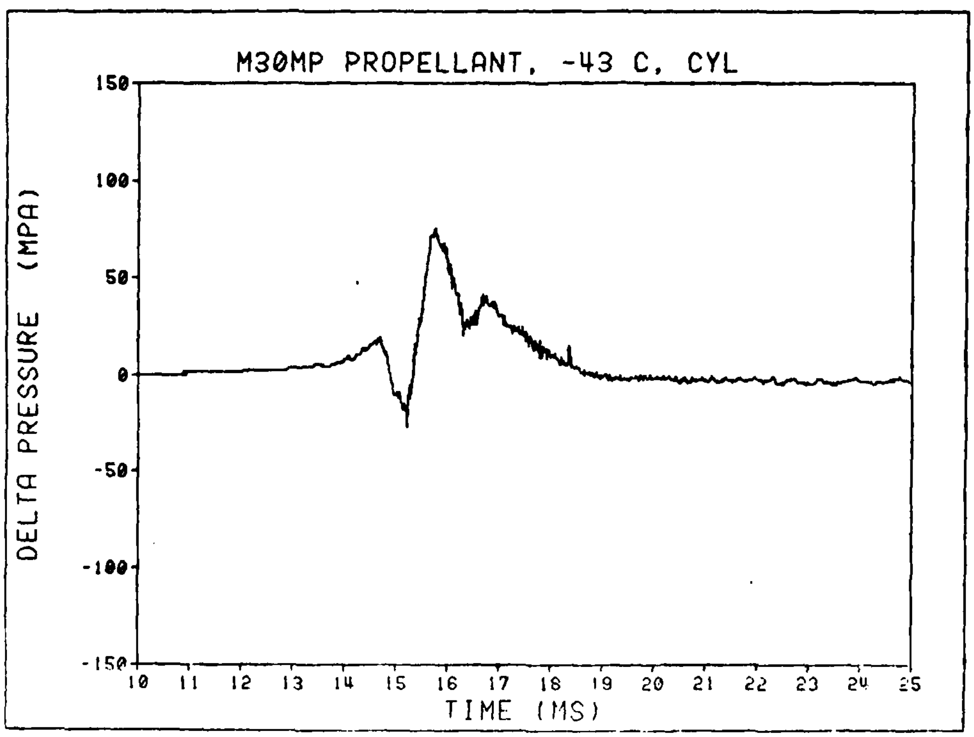
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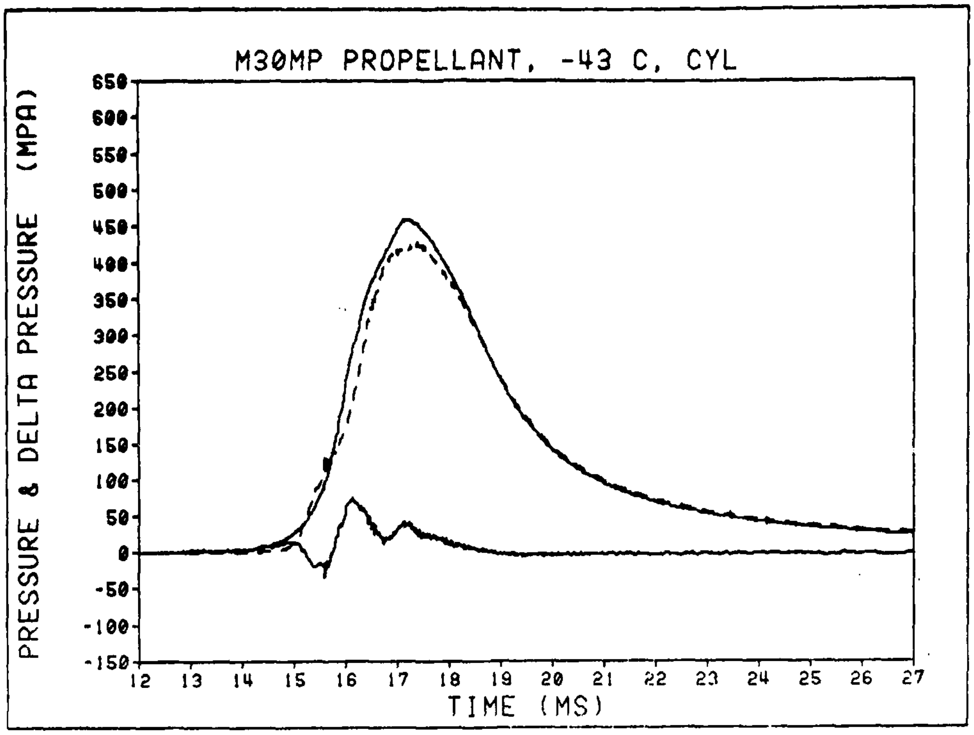
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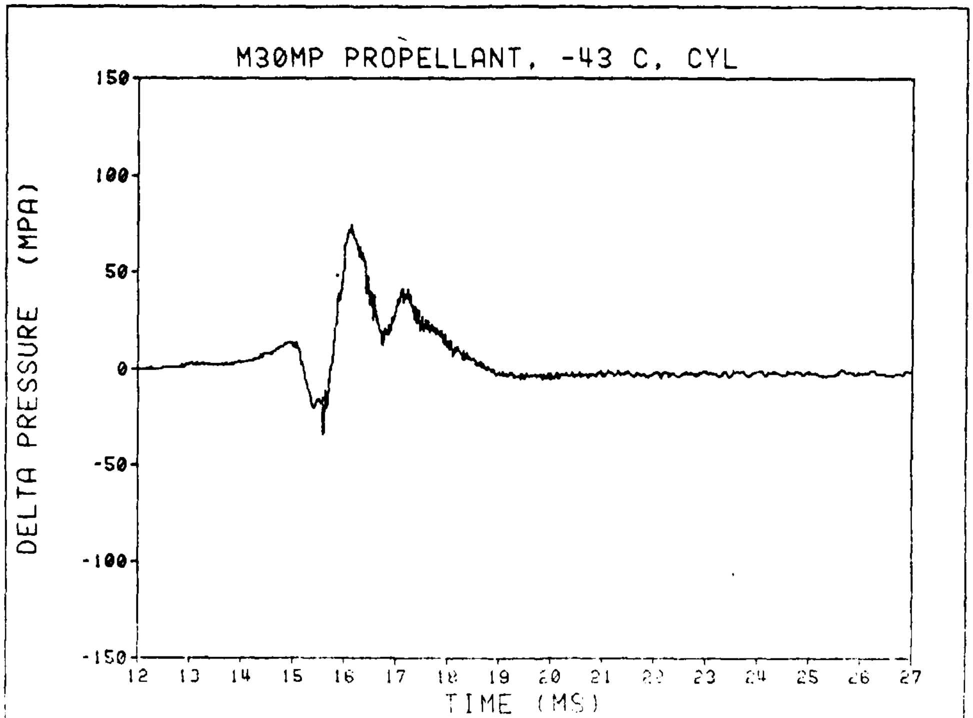
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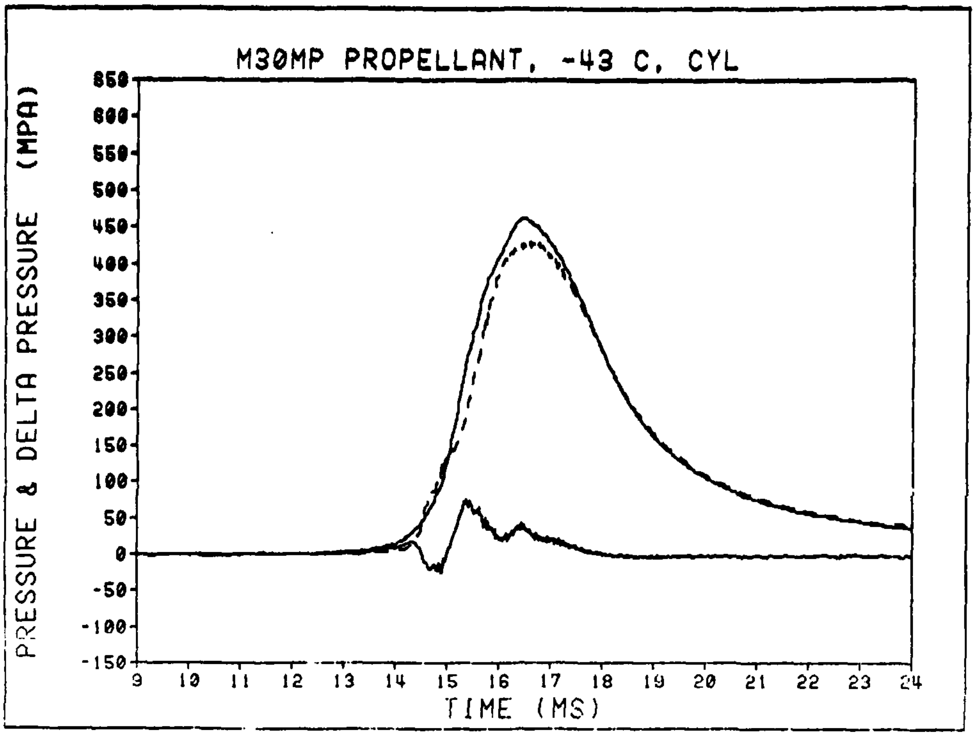
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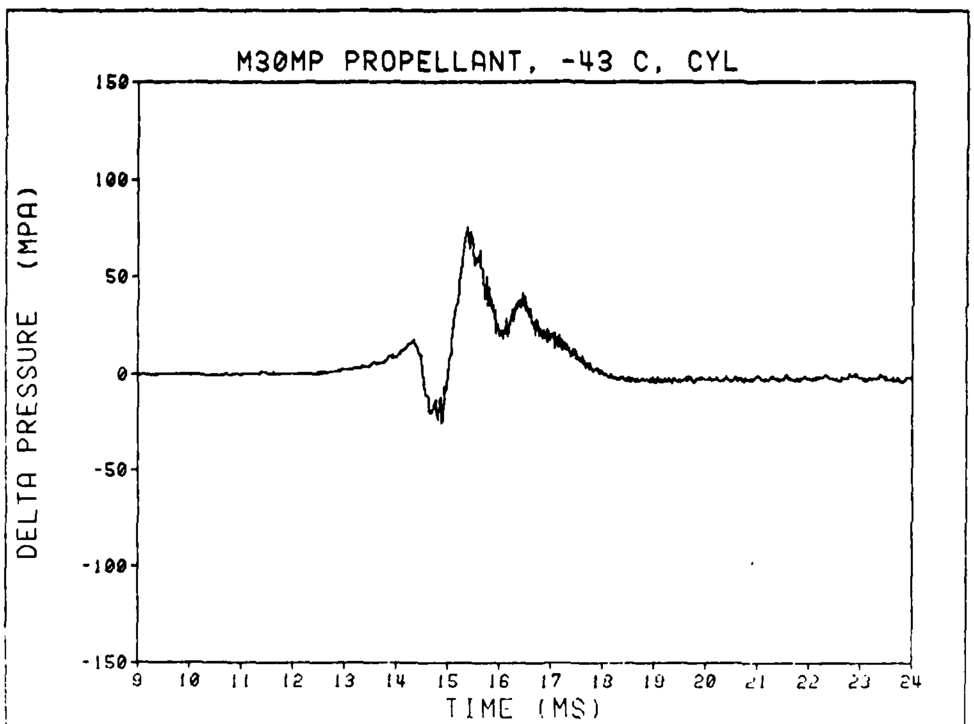
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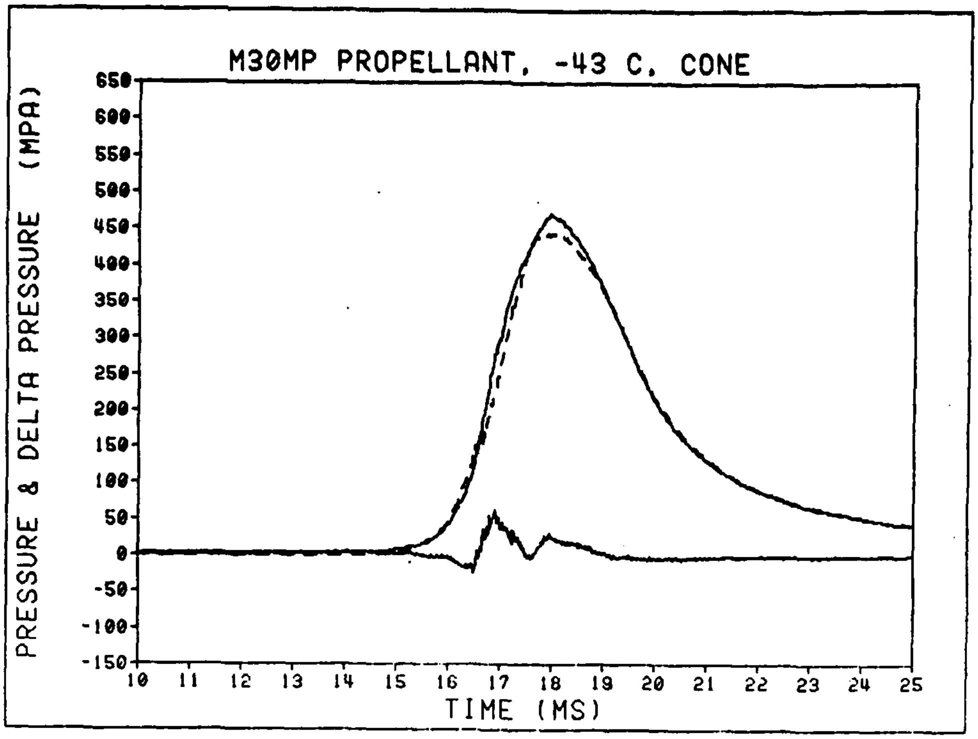
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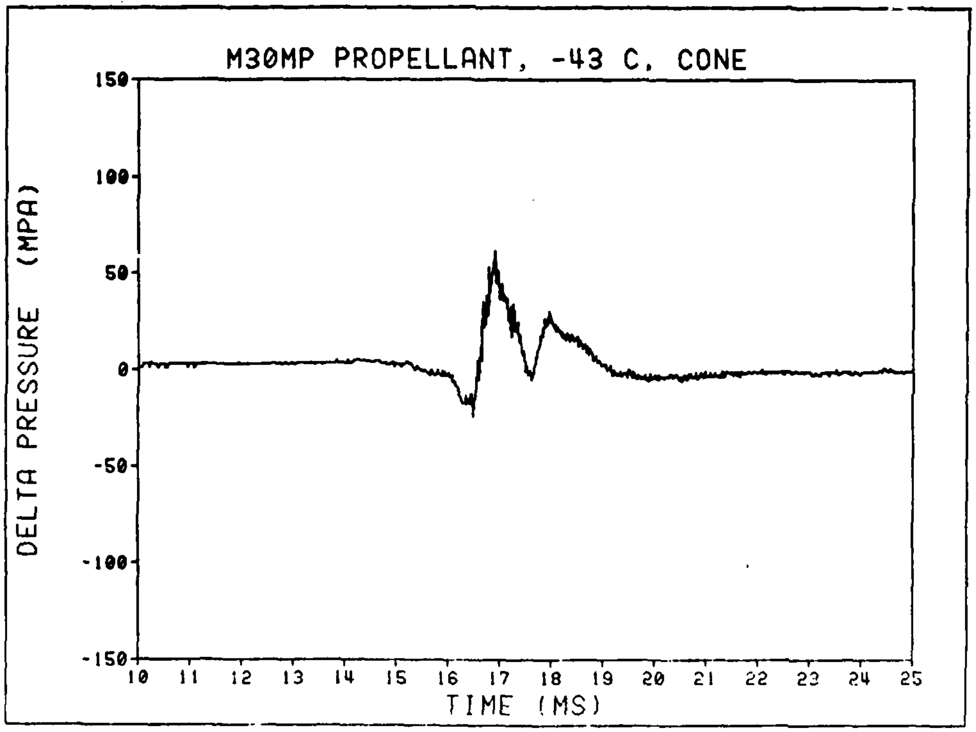
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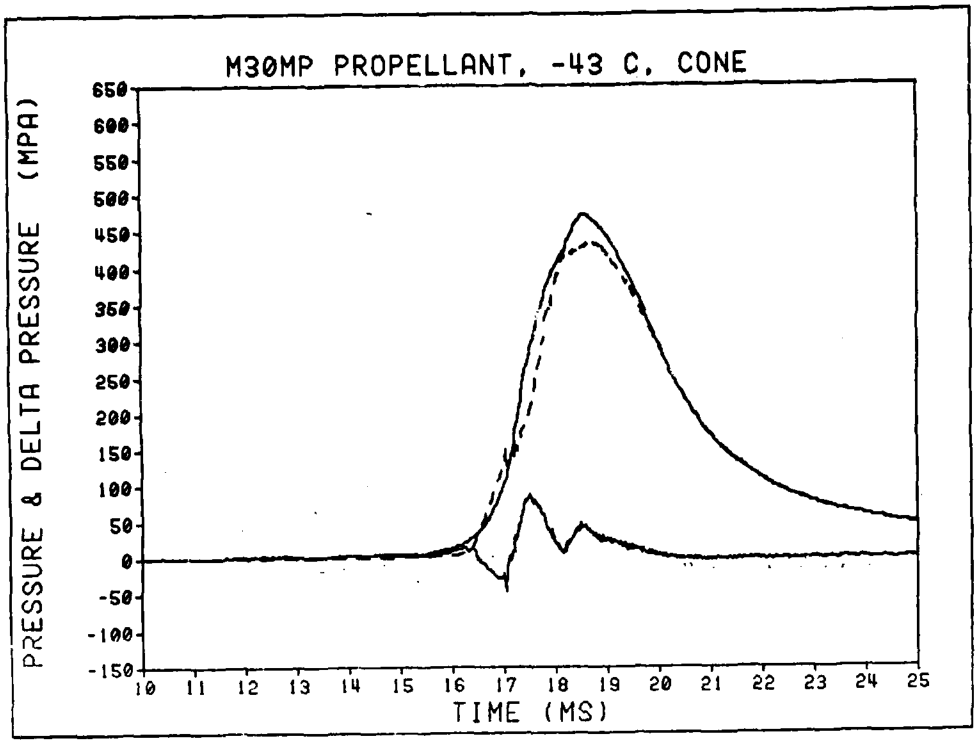

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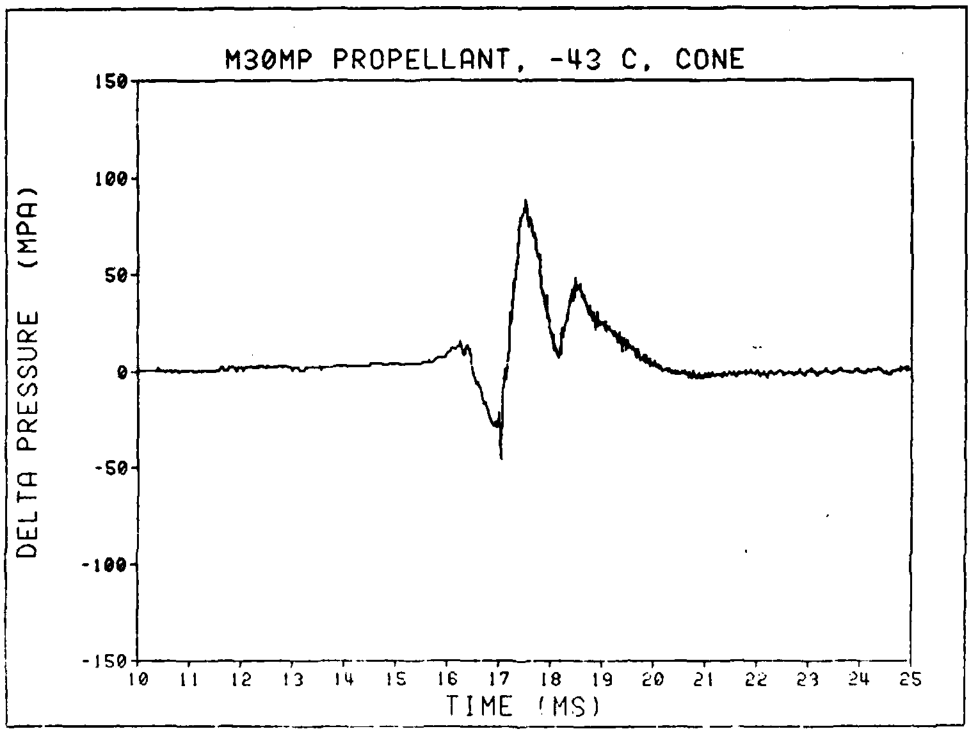

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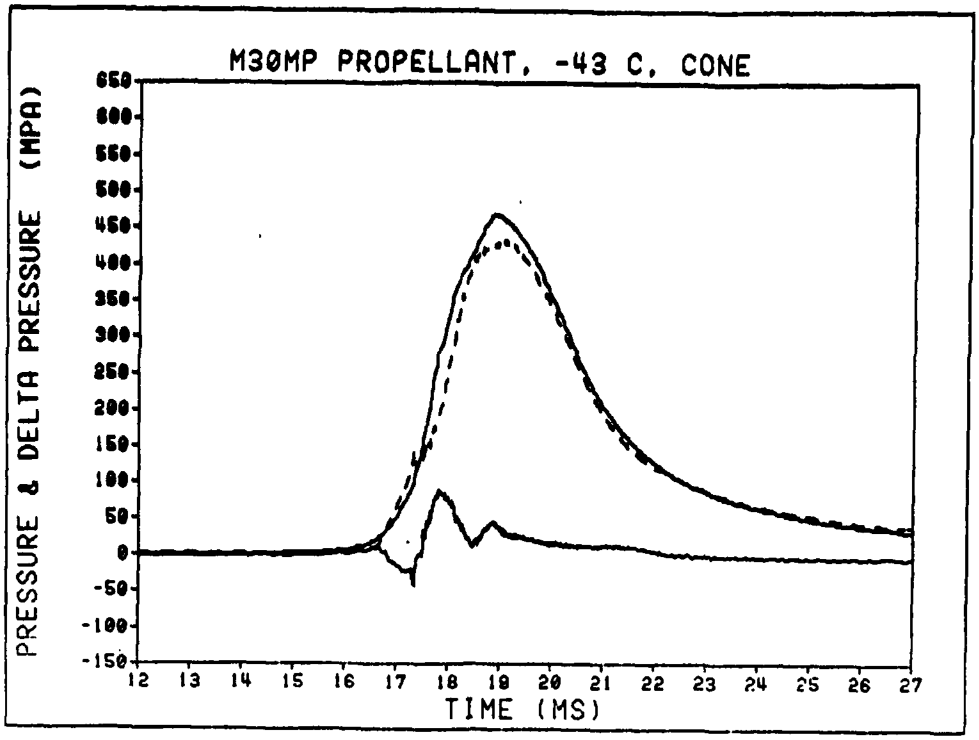
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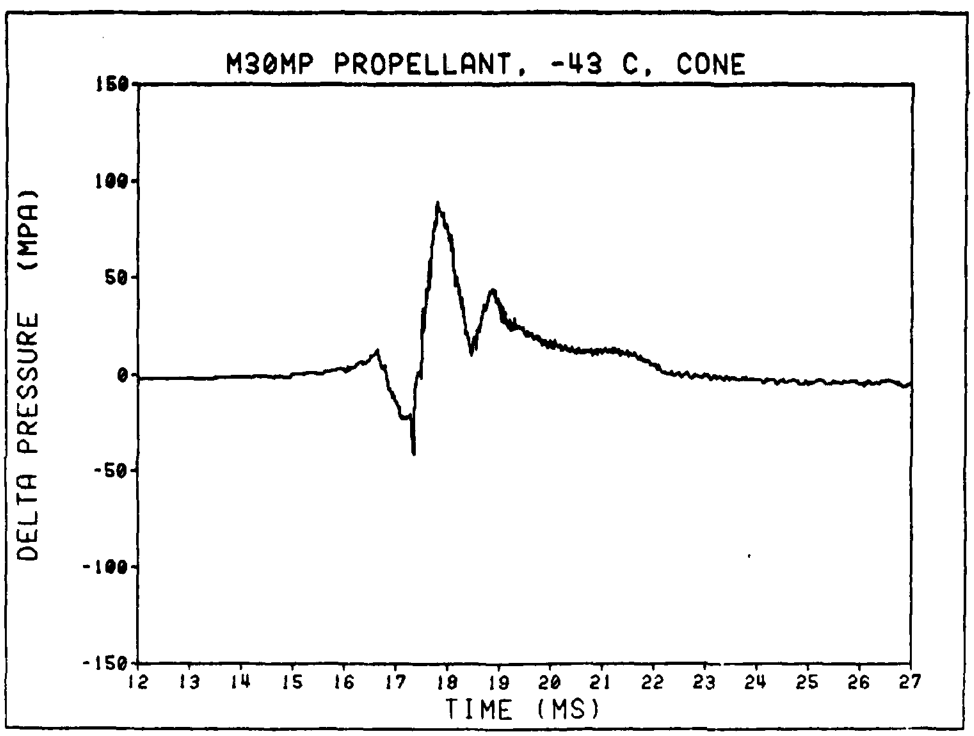
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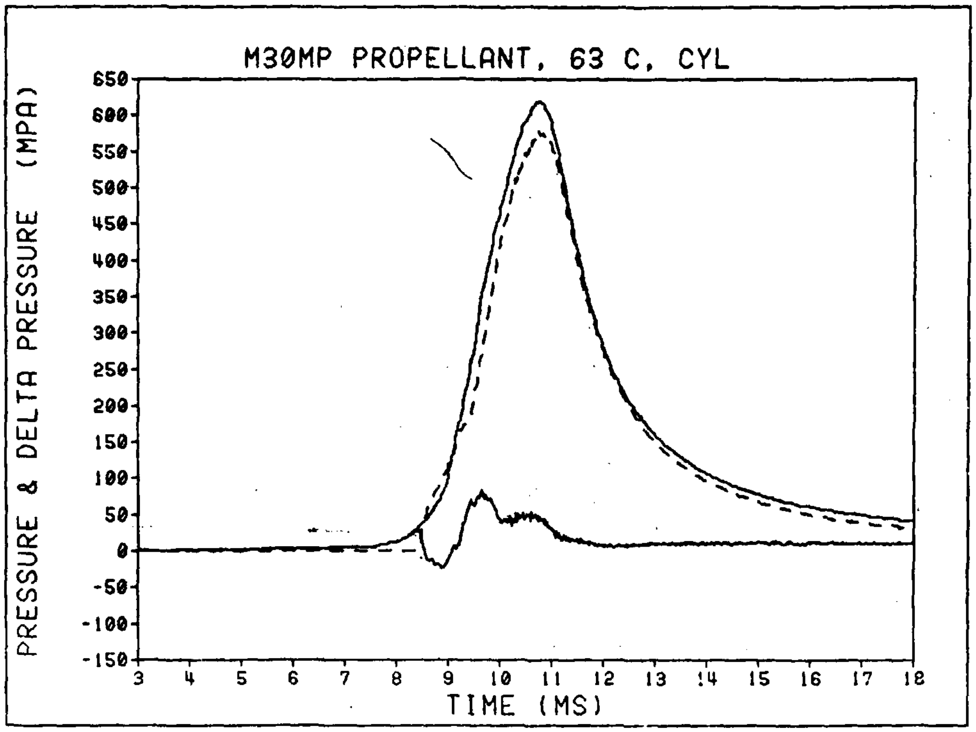
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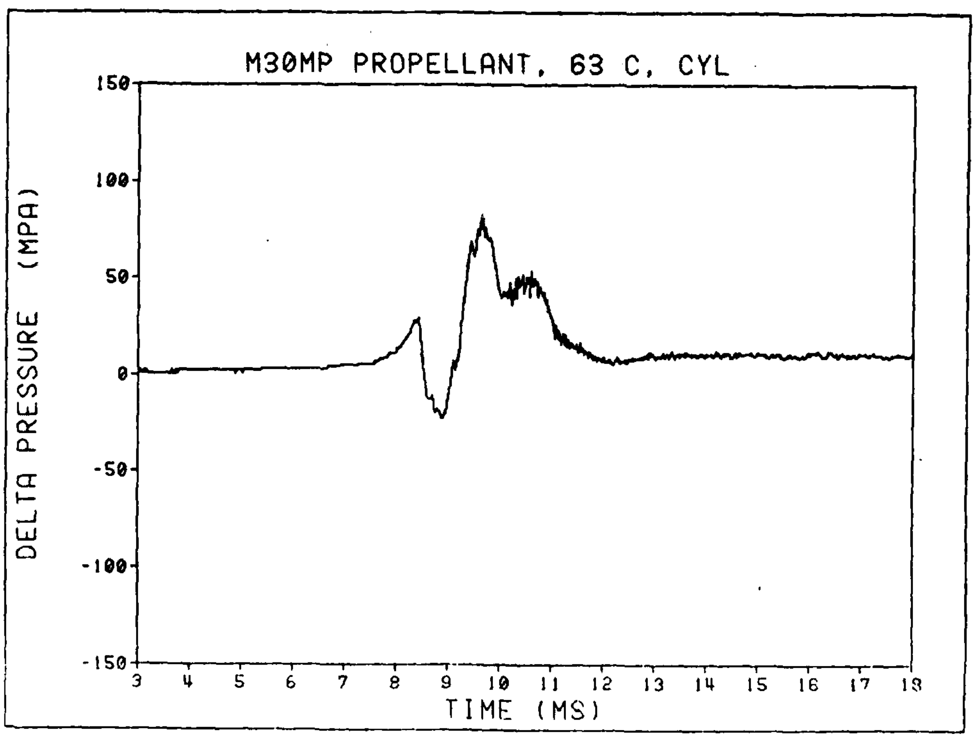
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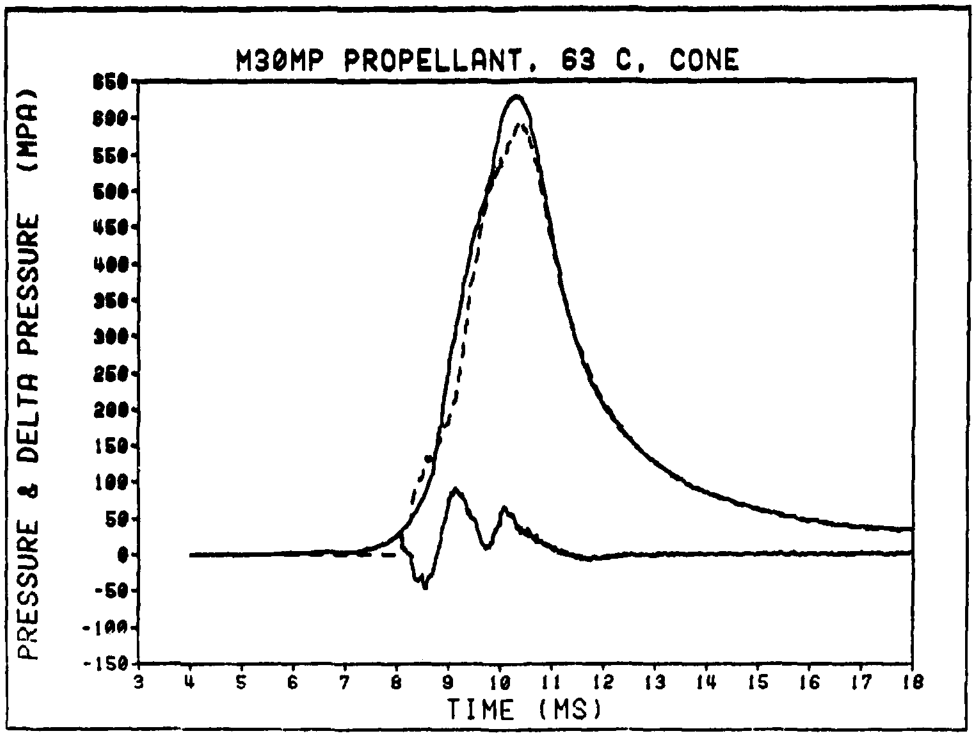

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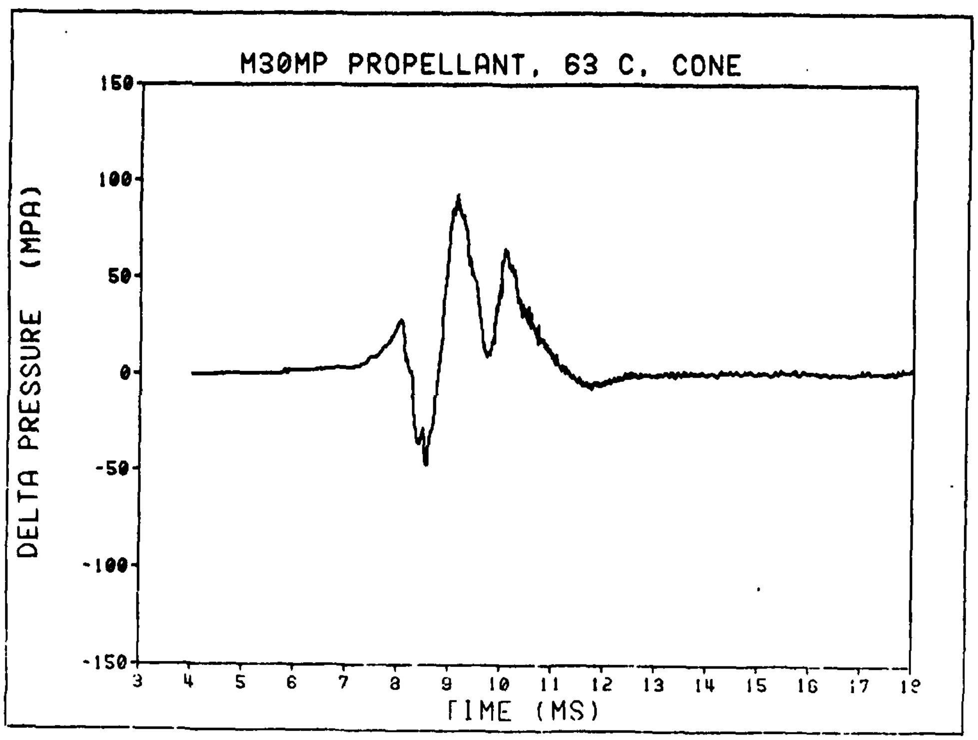

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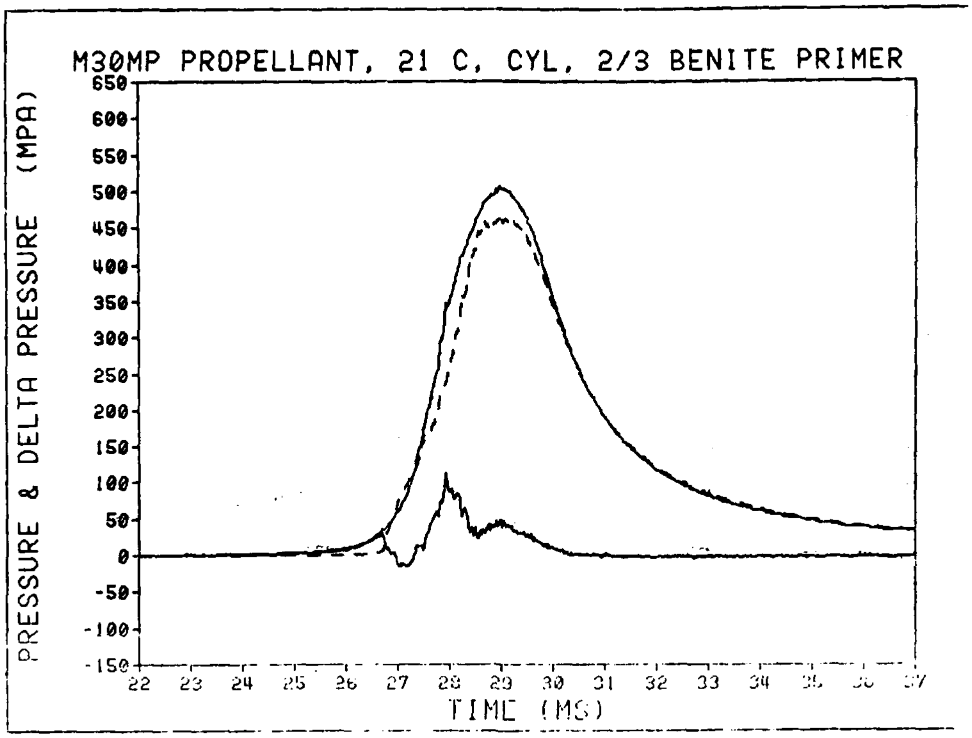
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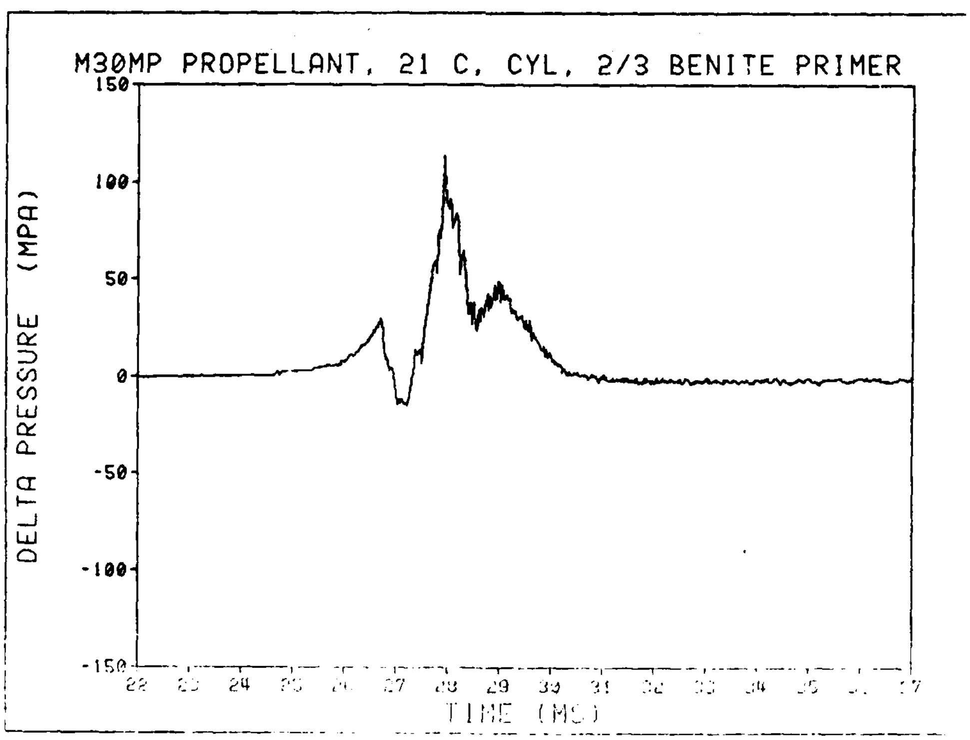
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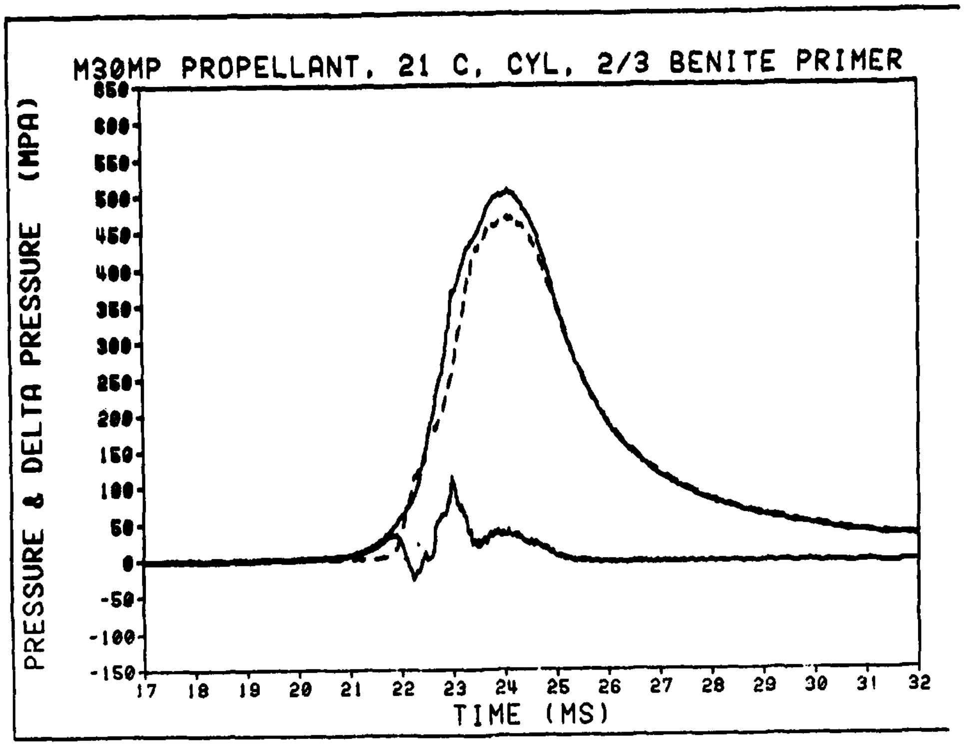

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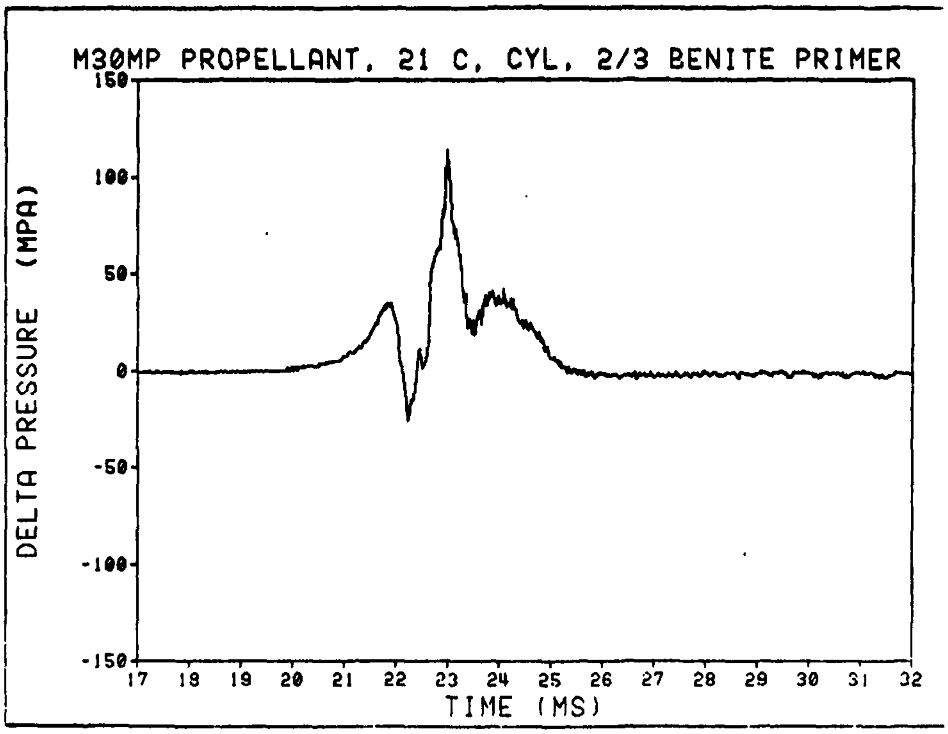
TIME (MS)



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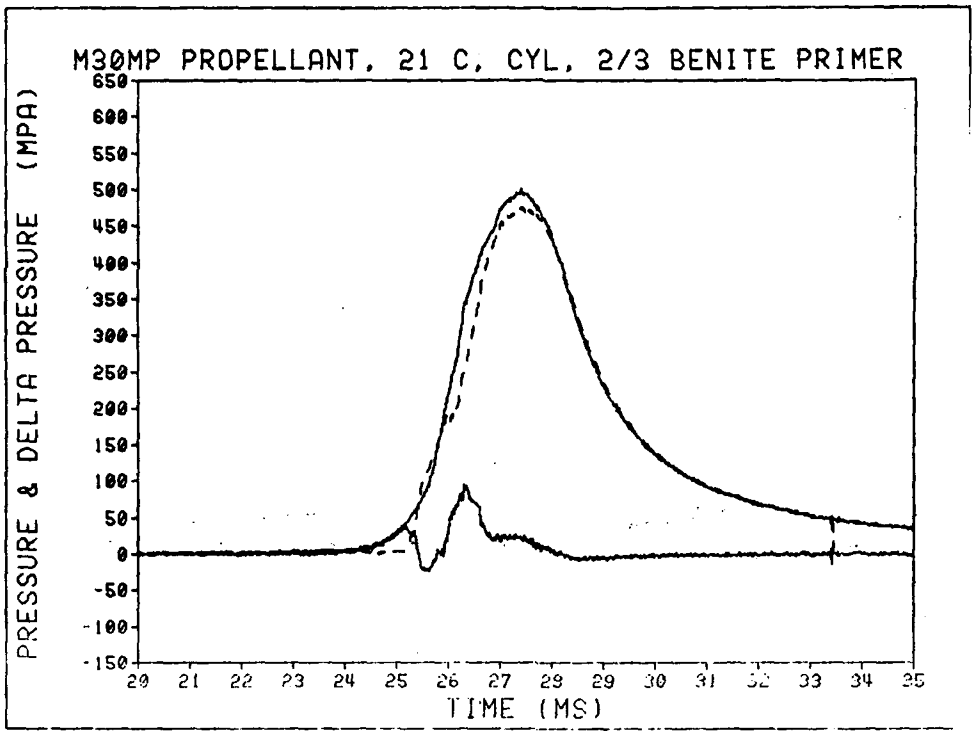
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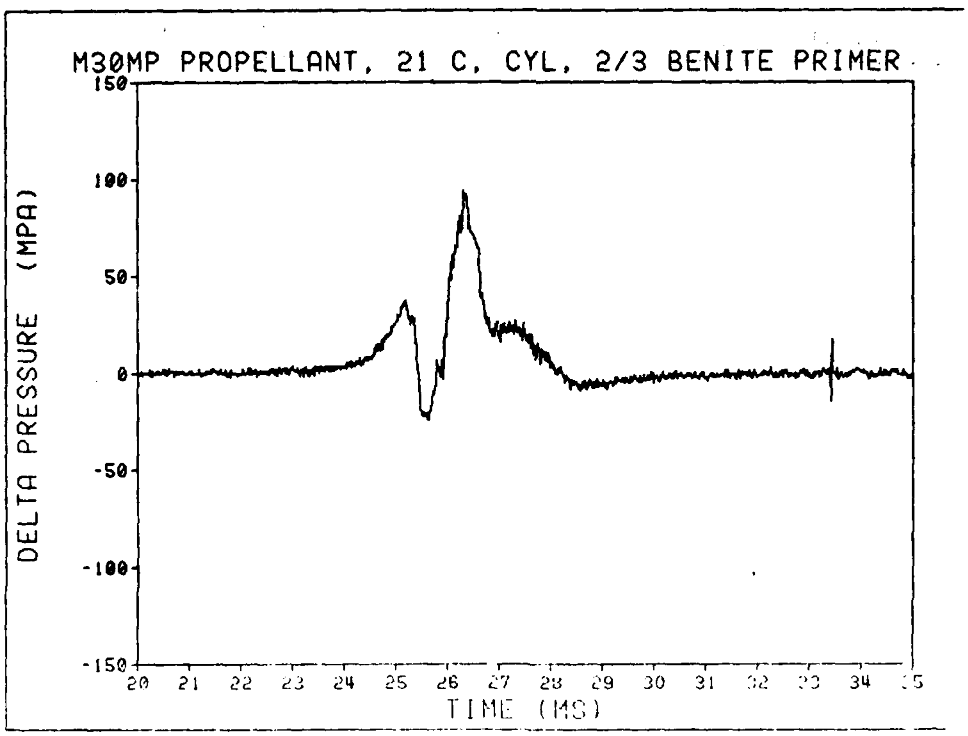
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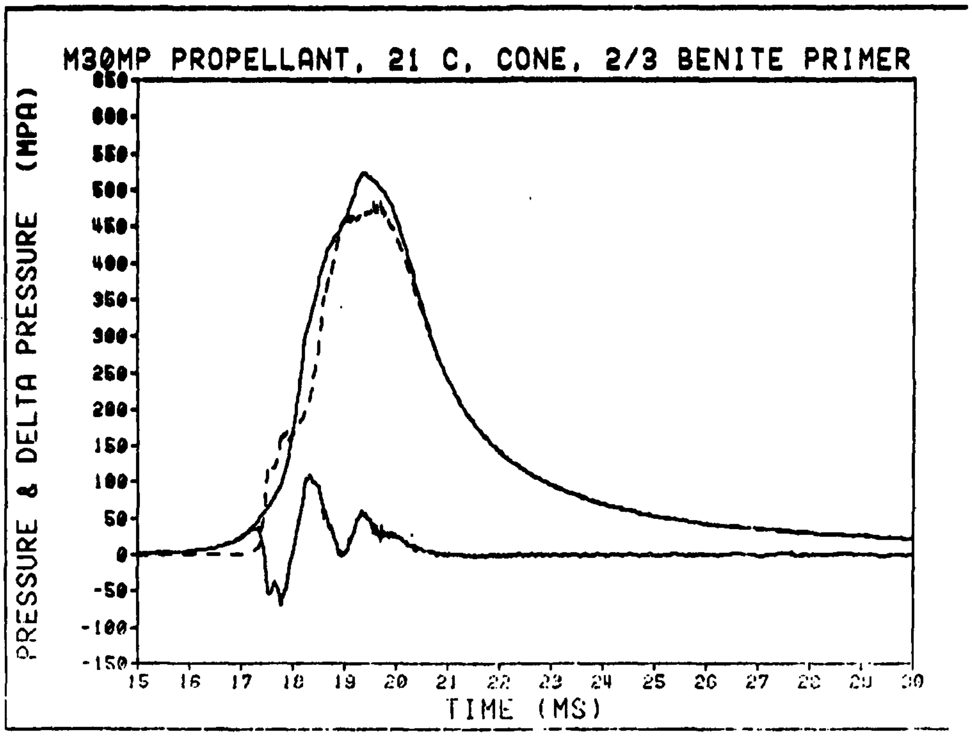
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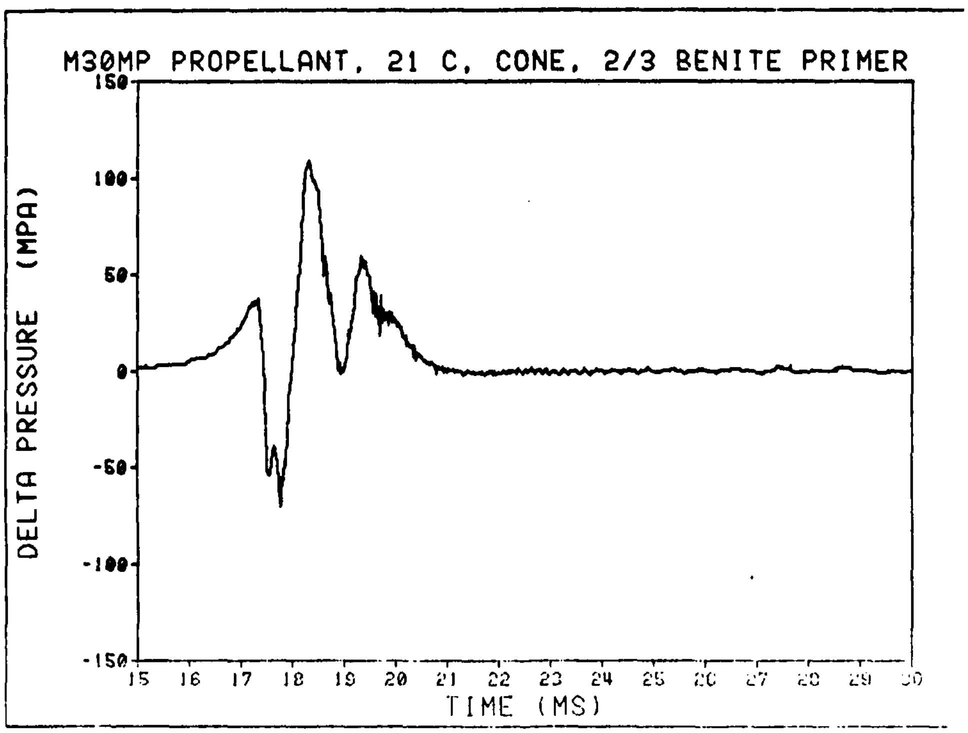
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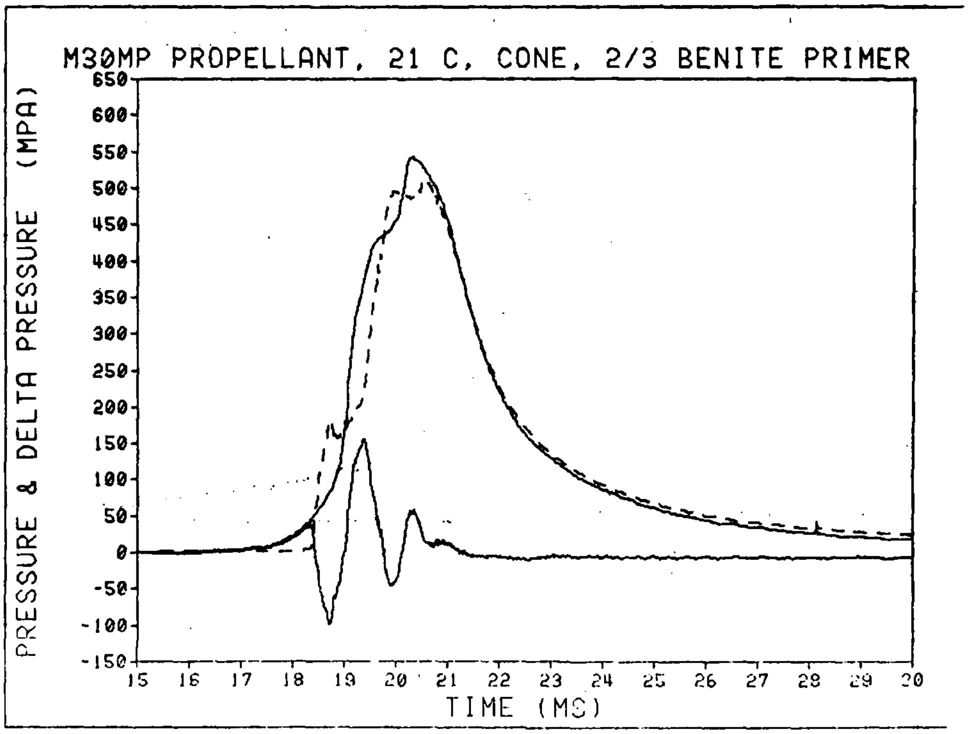
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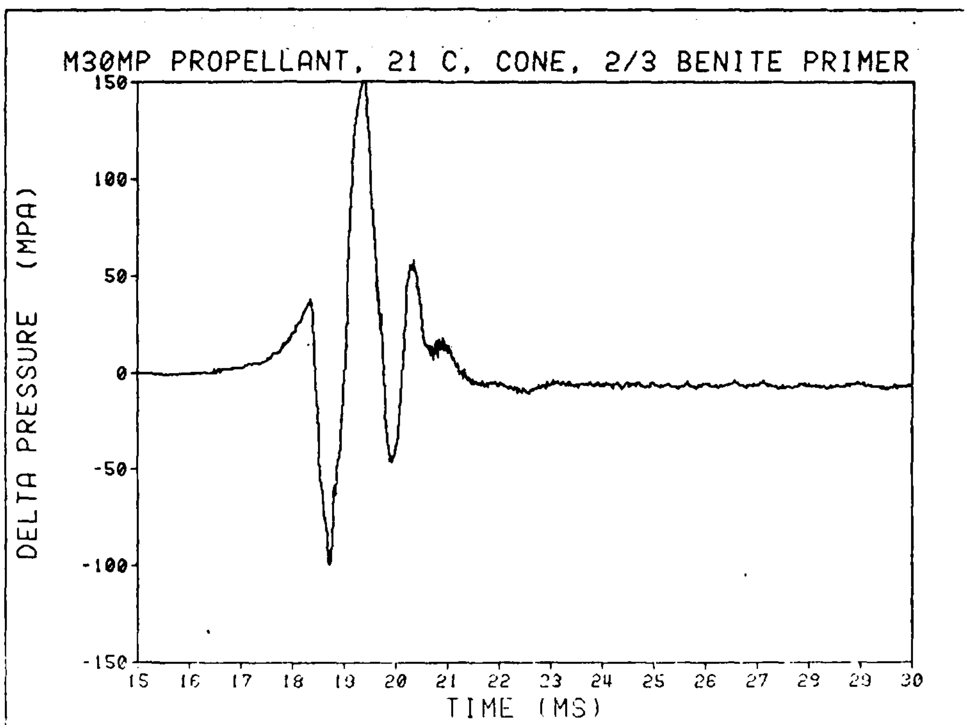
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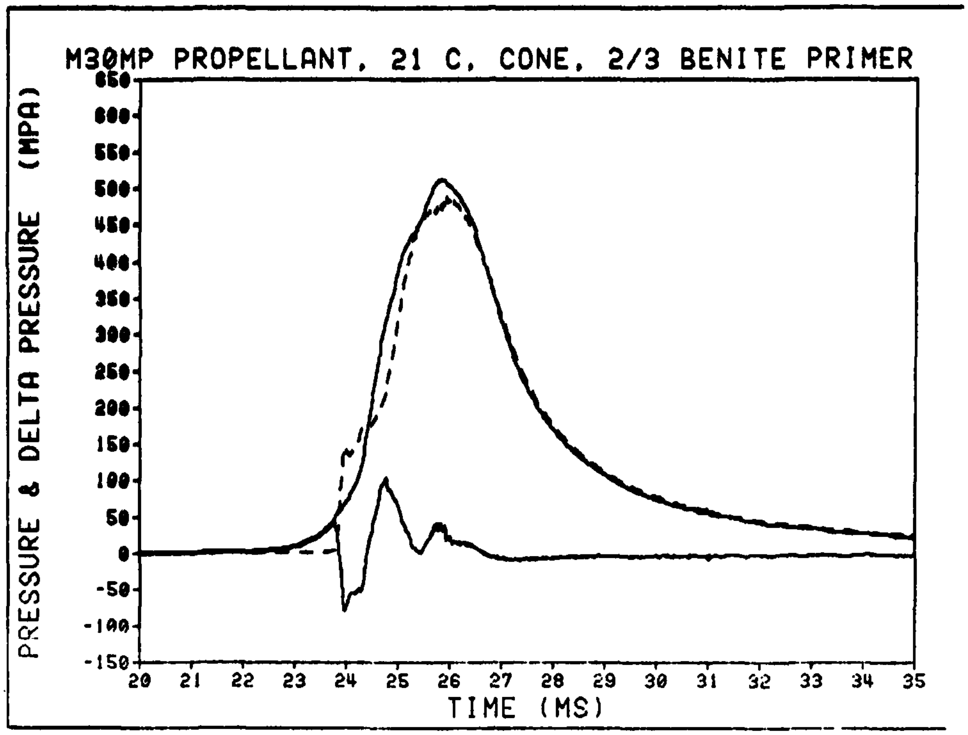

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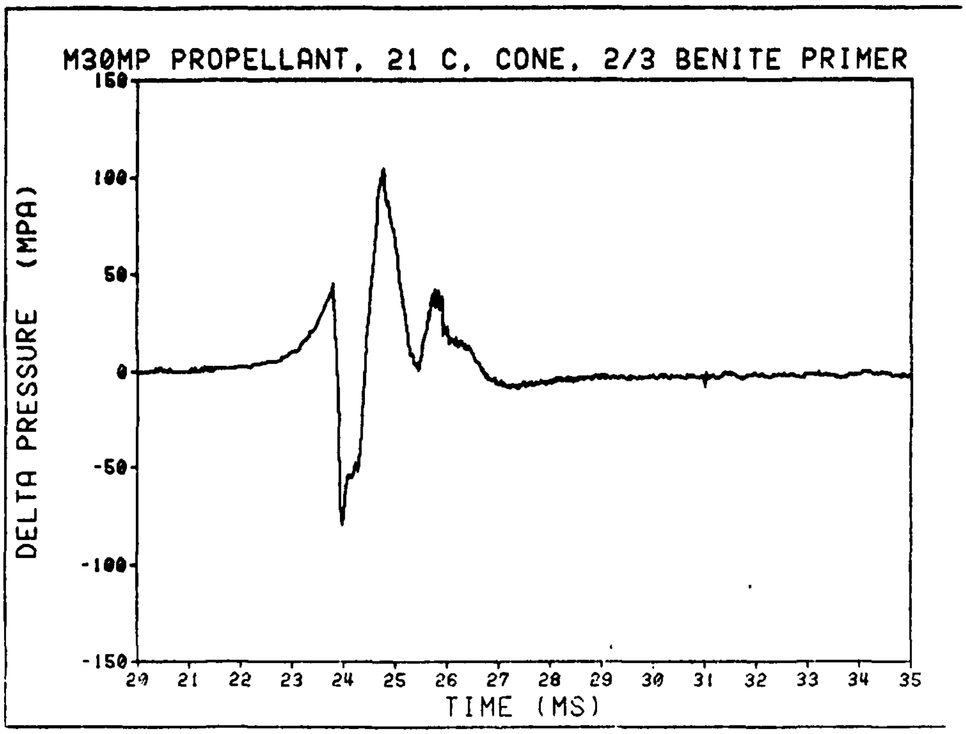

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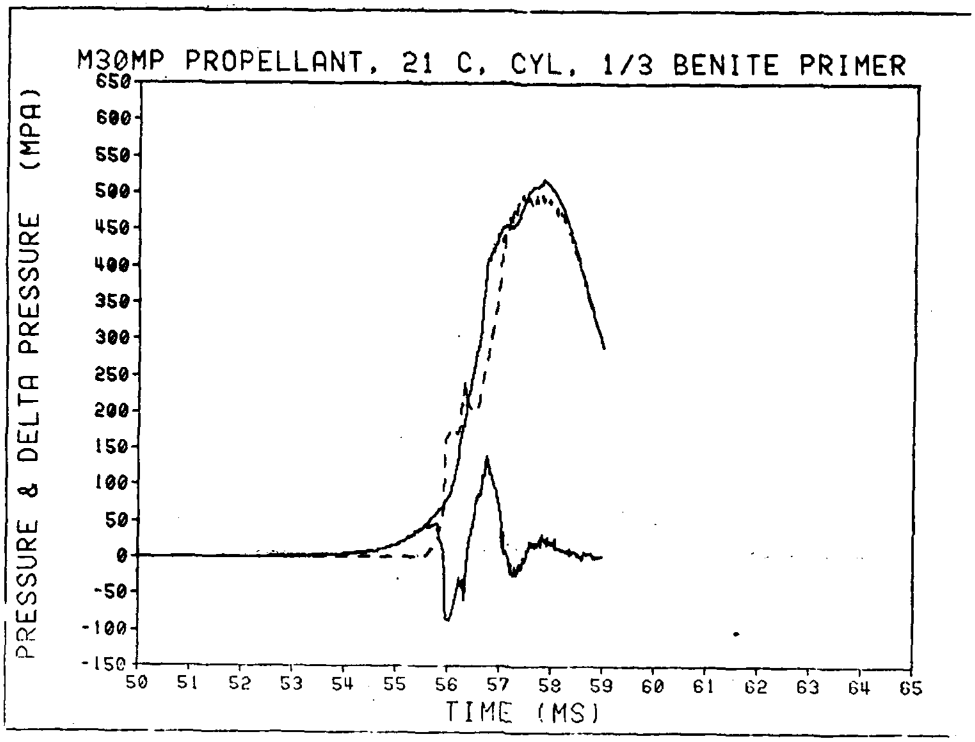
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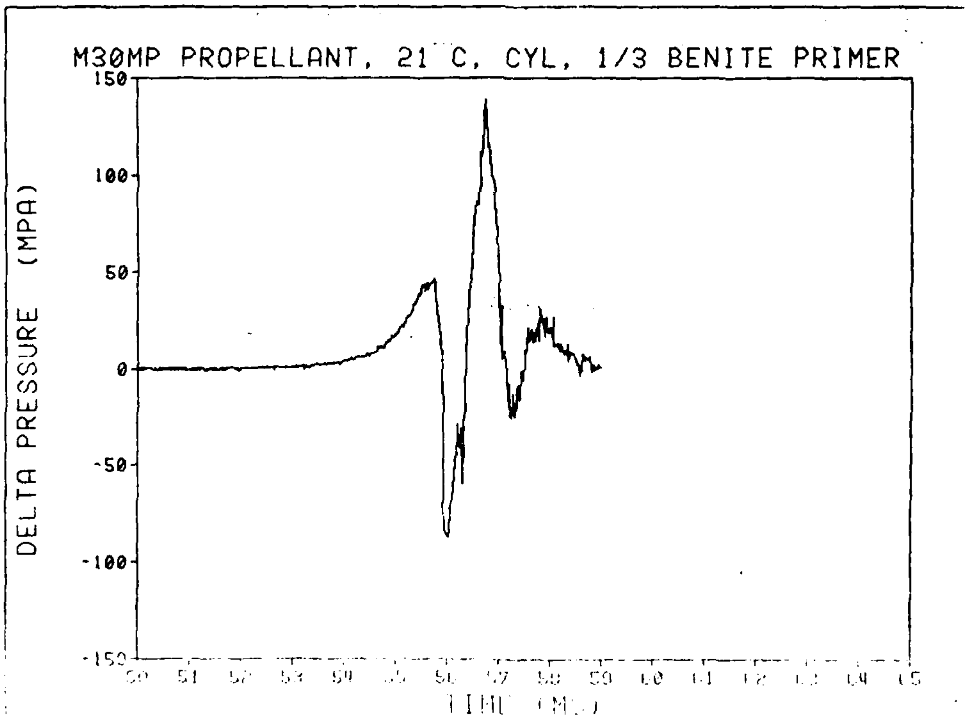
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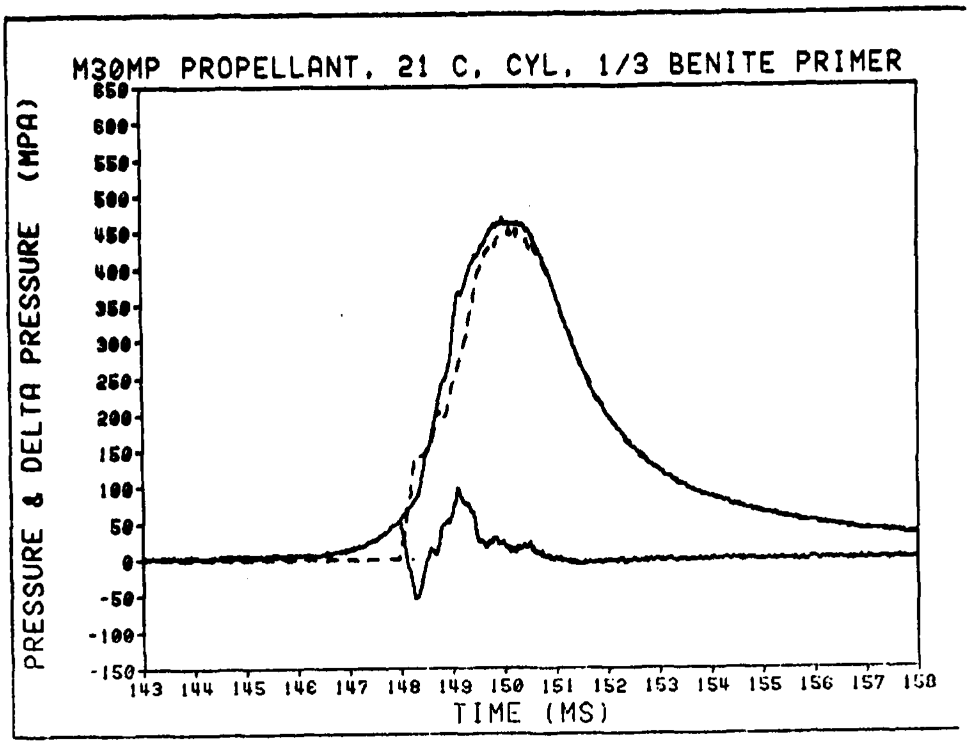
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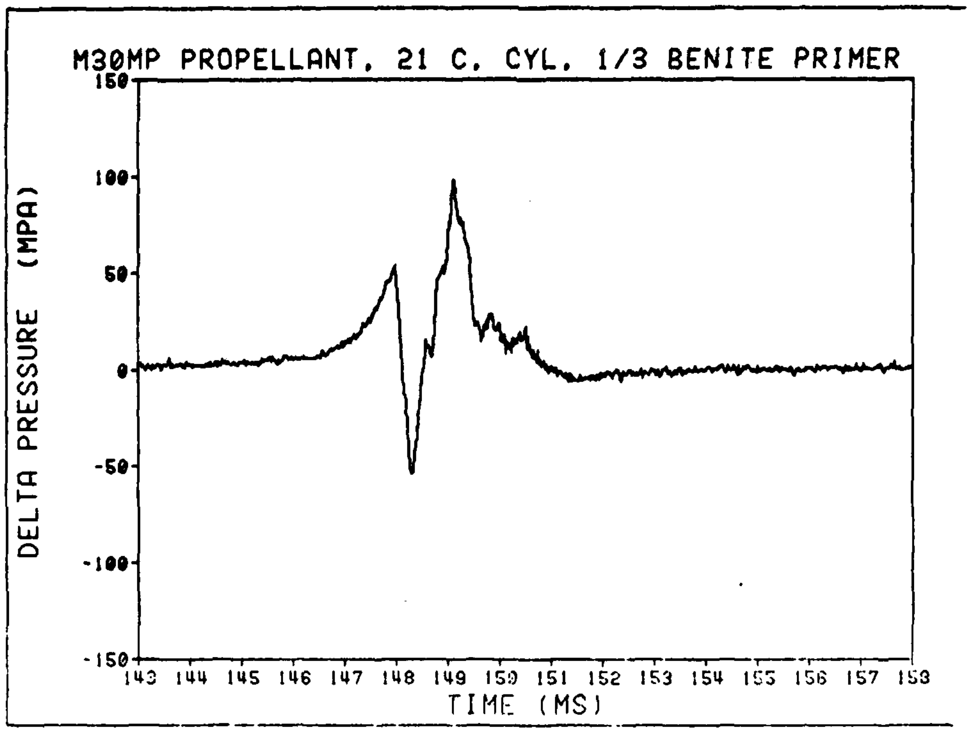
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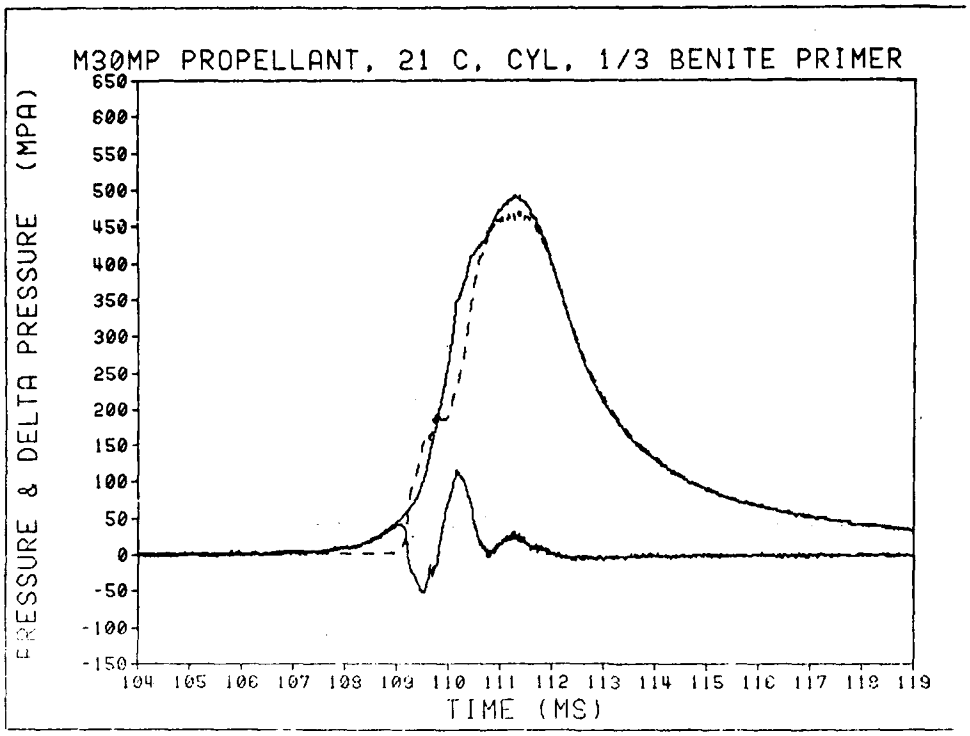

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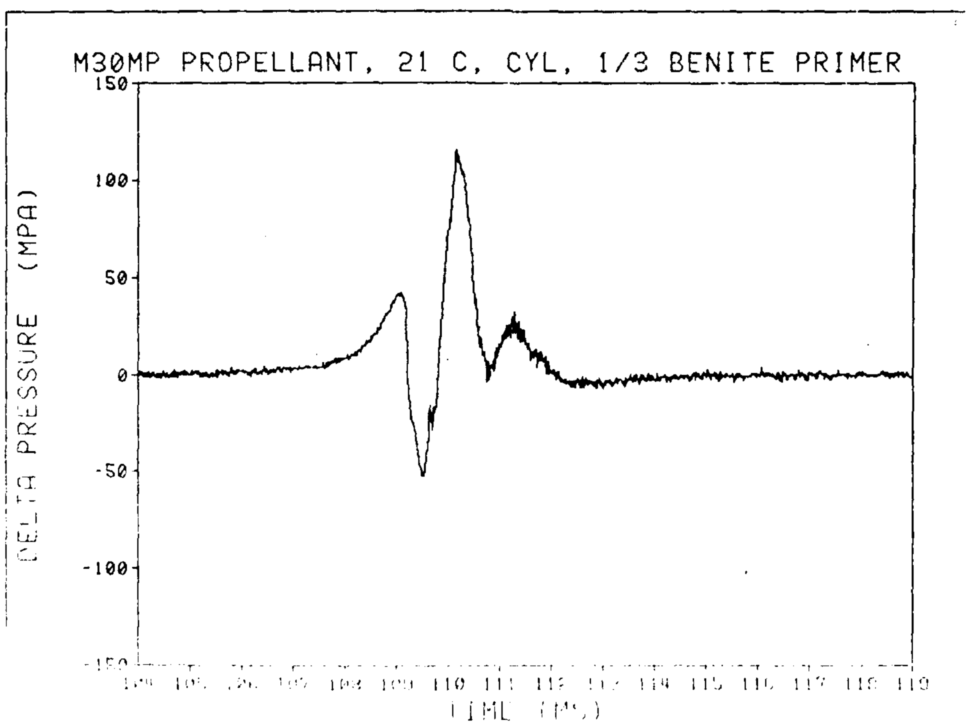

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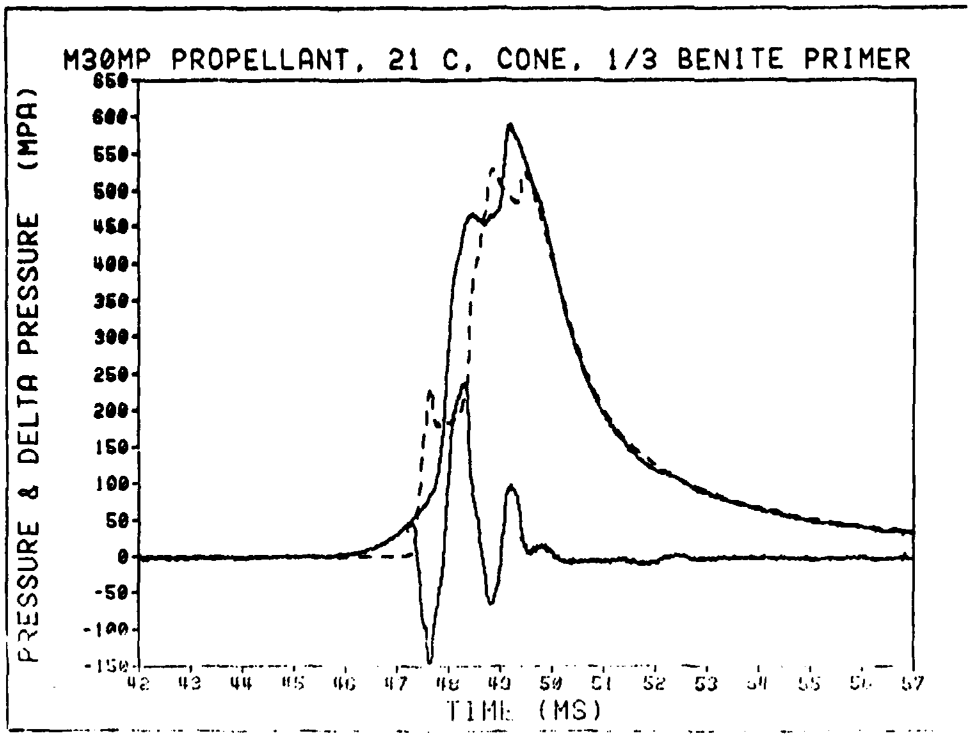
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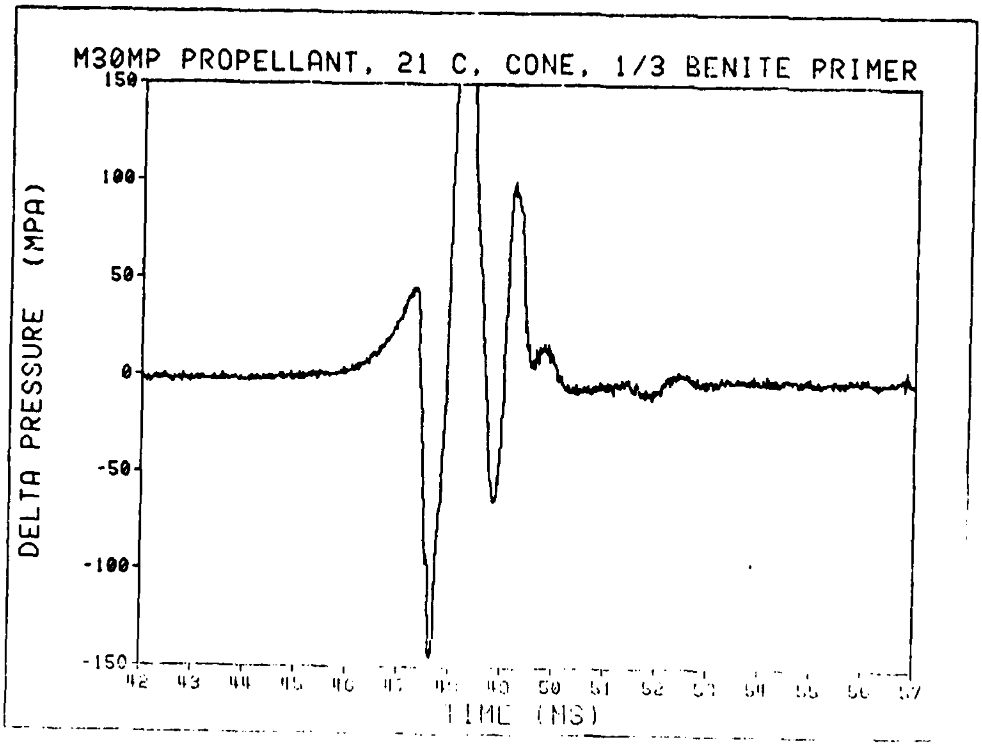
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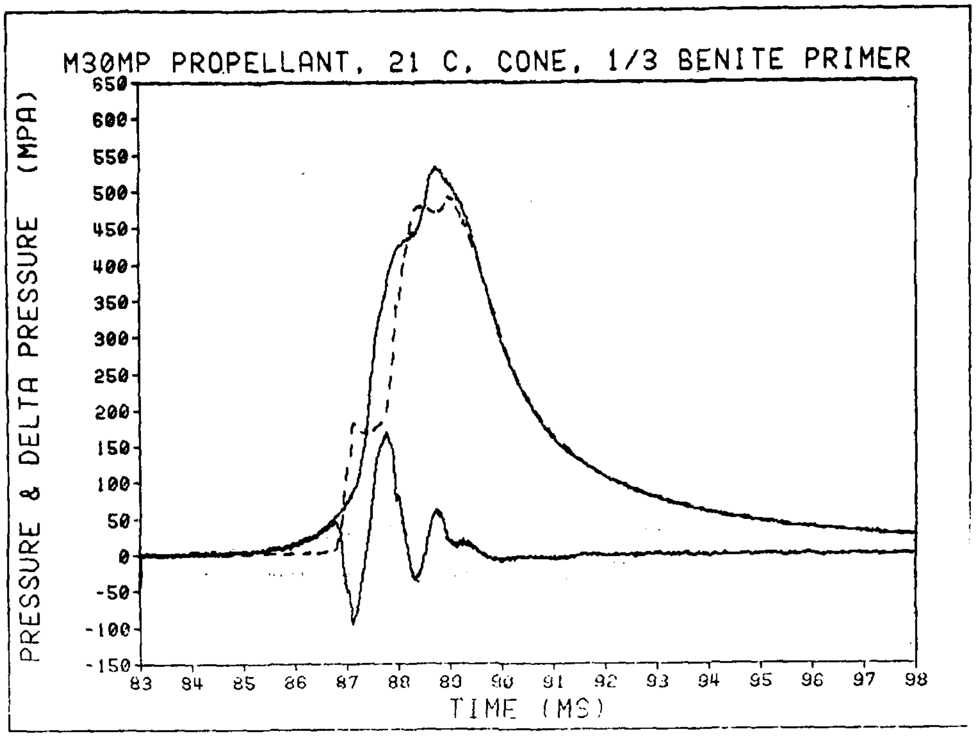
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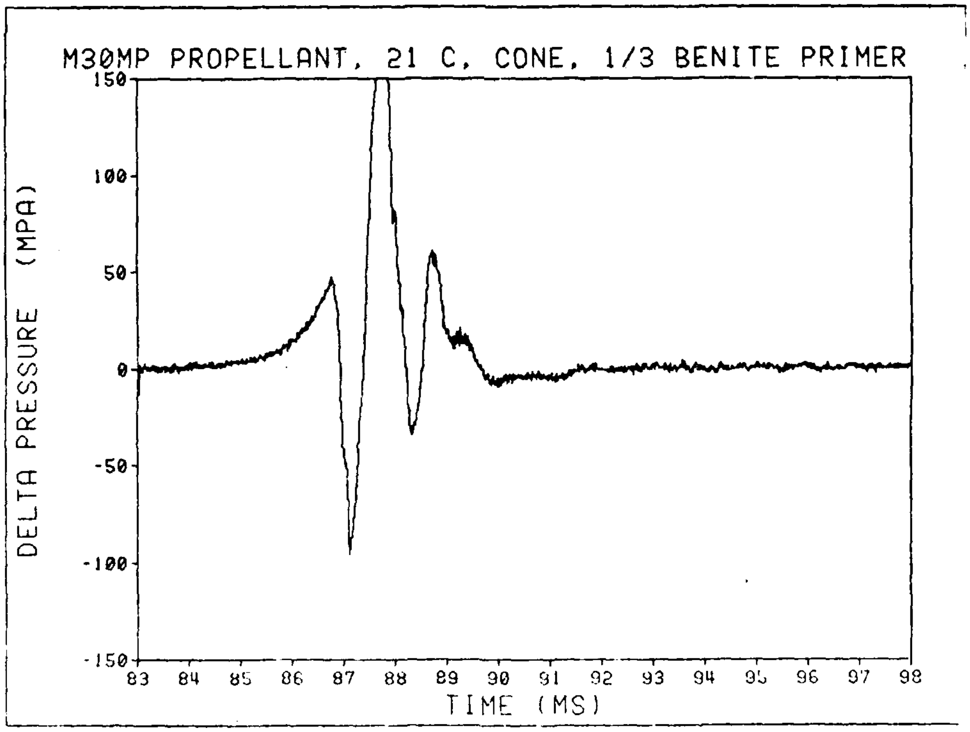
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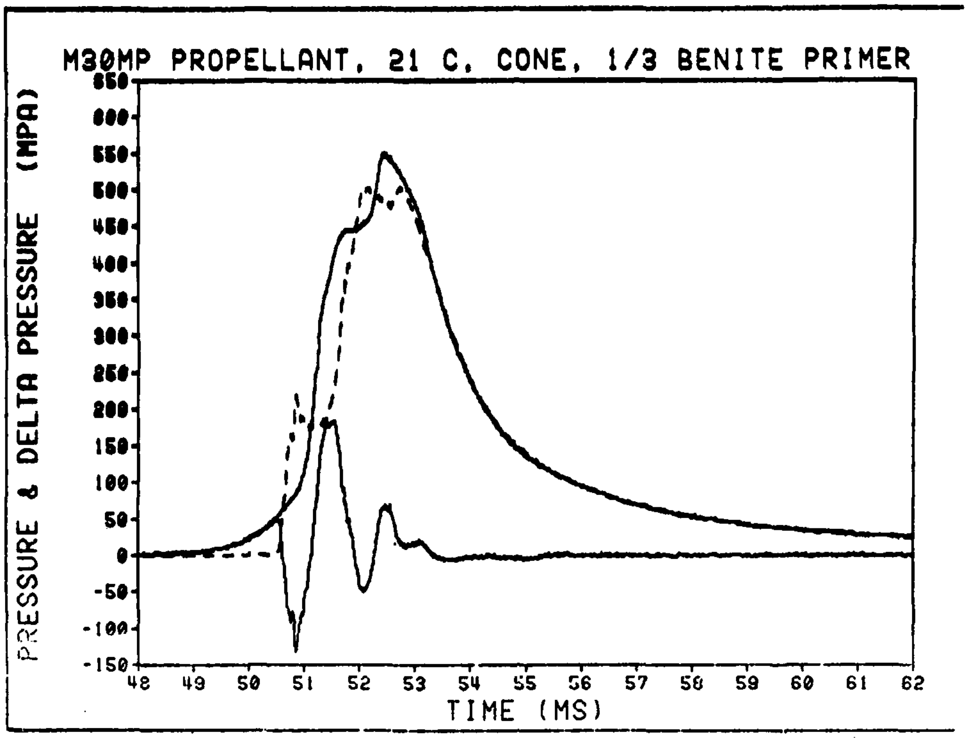
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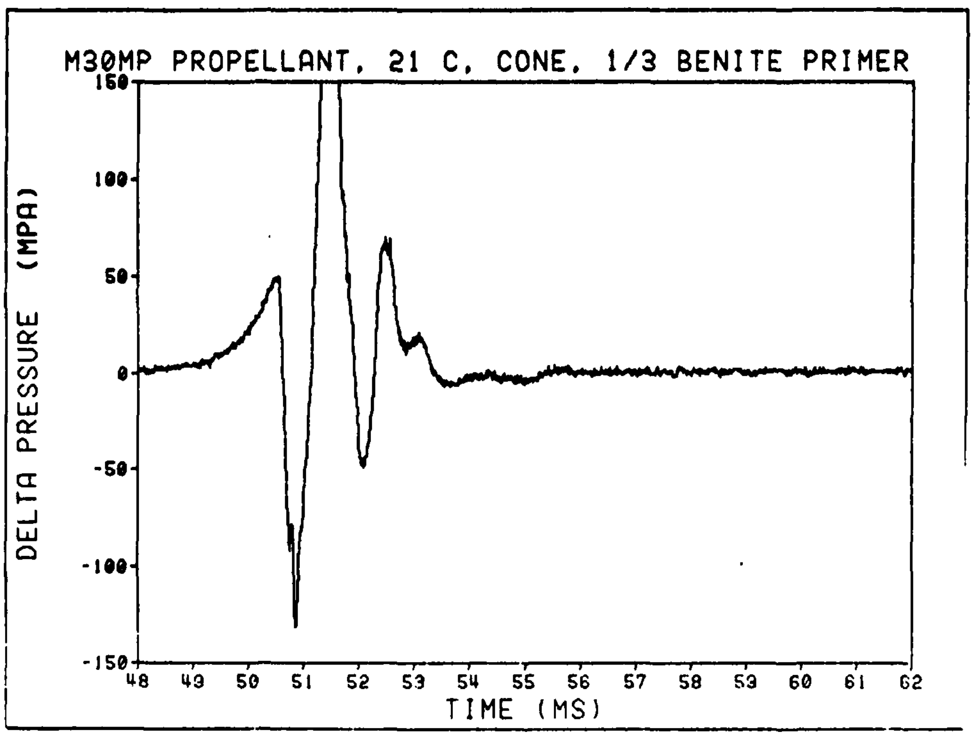
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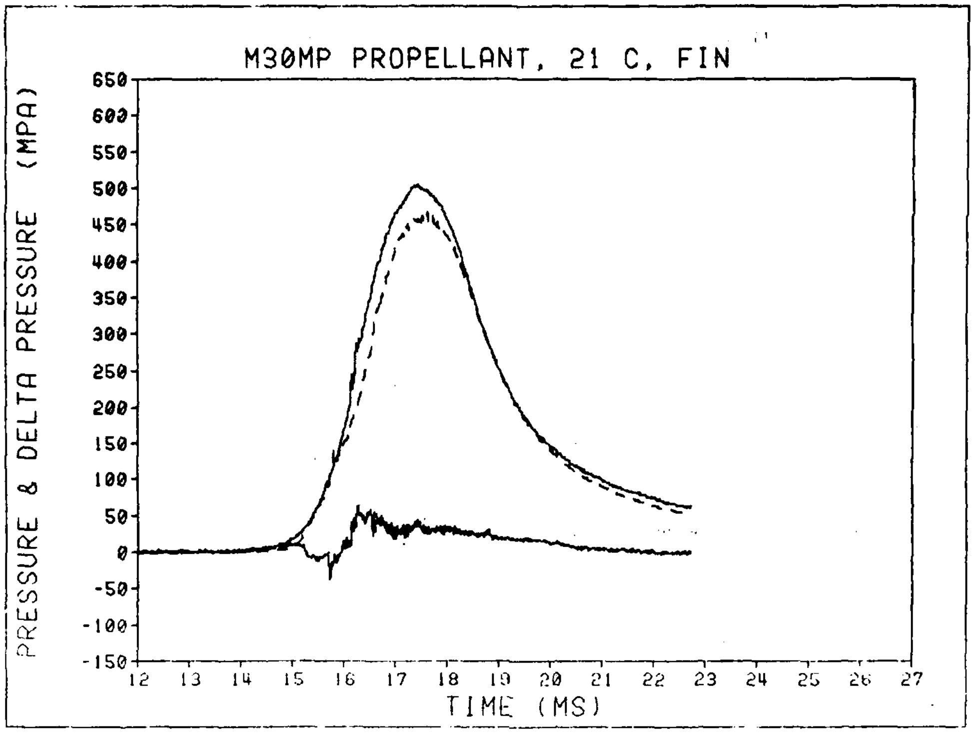
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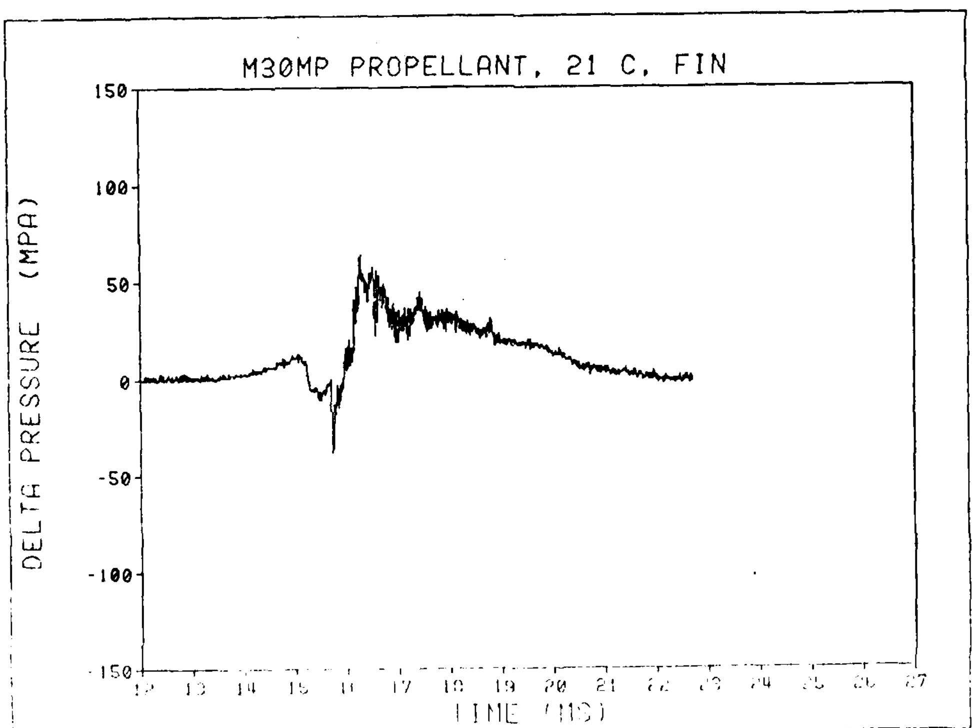
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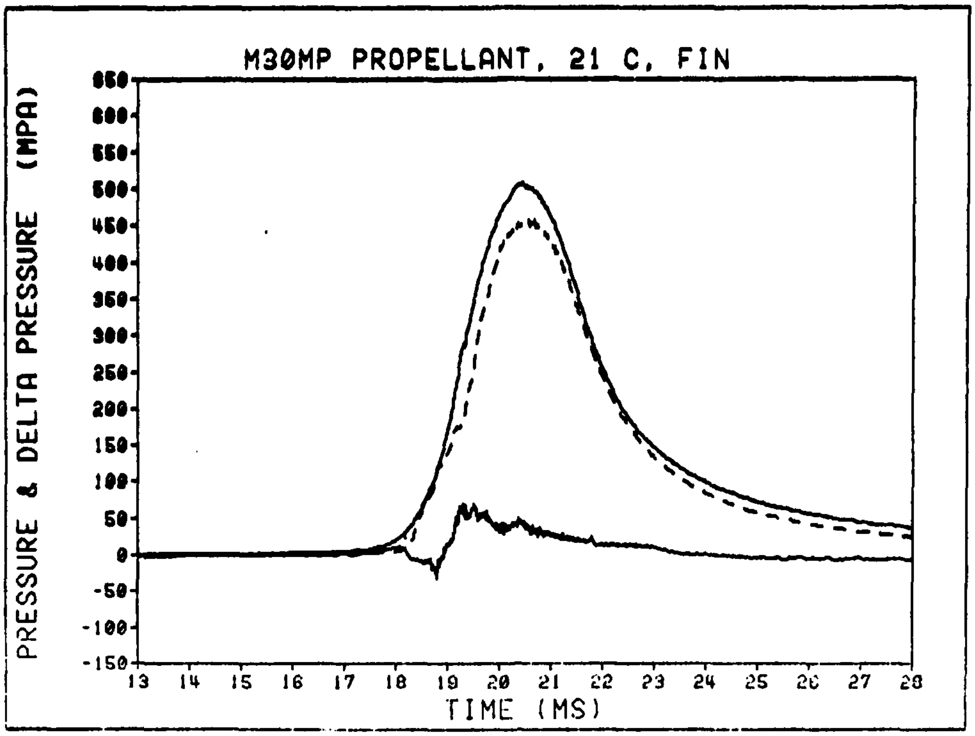
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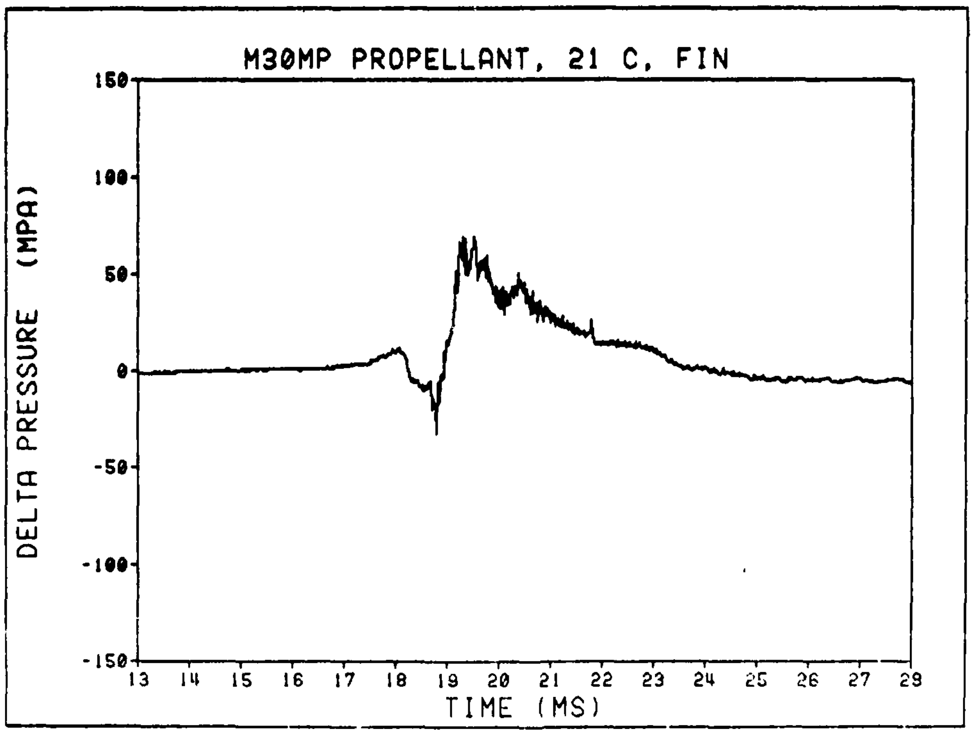
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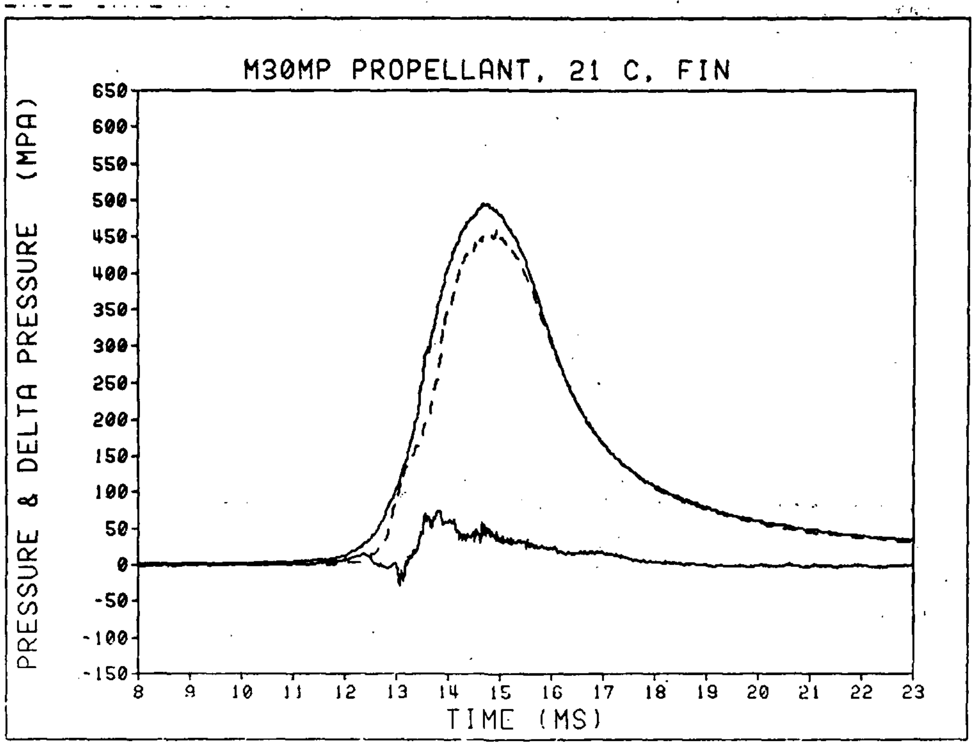
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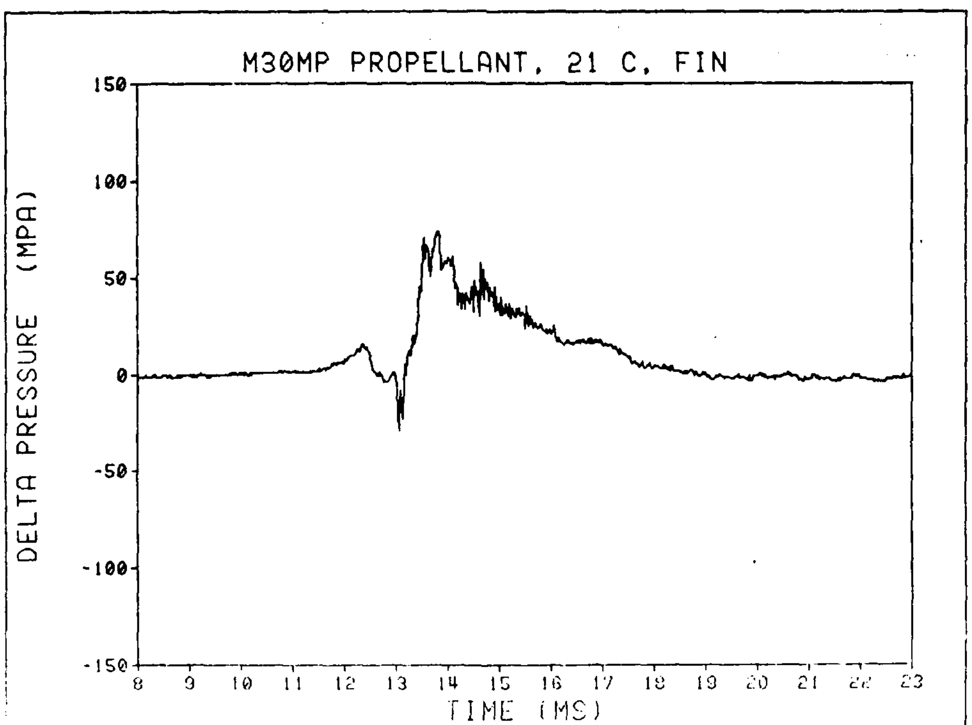
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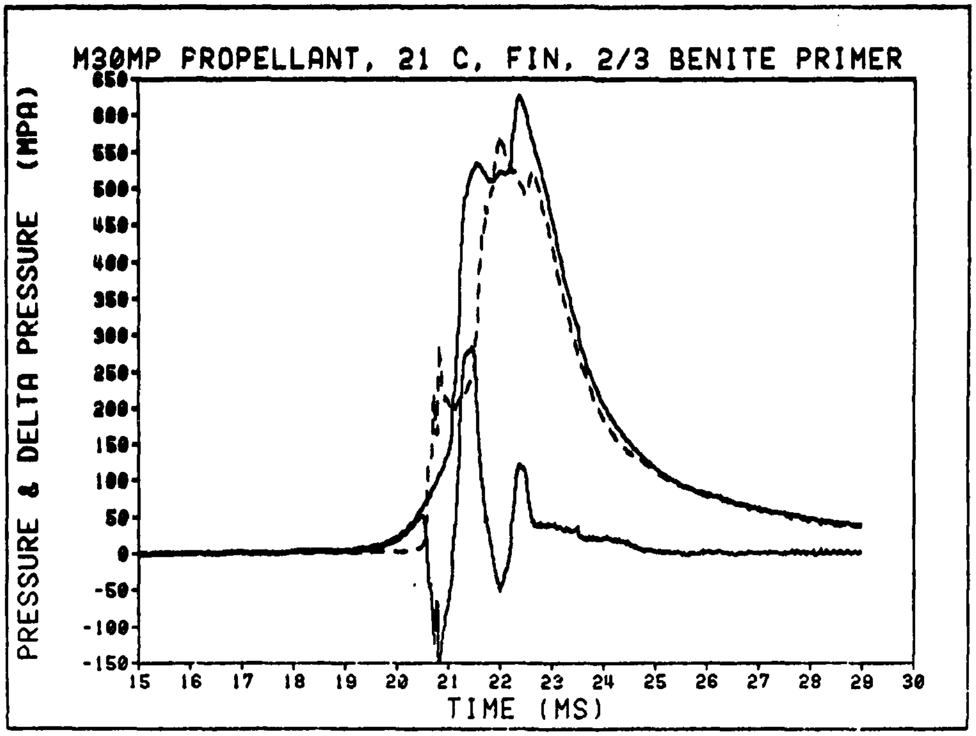
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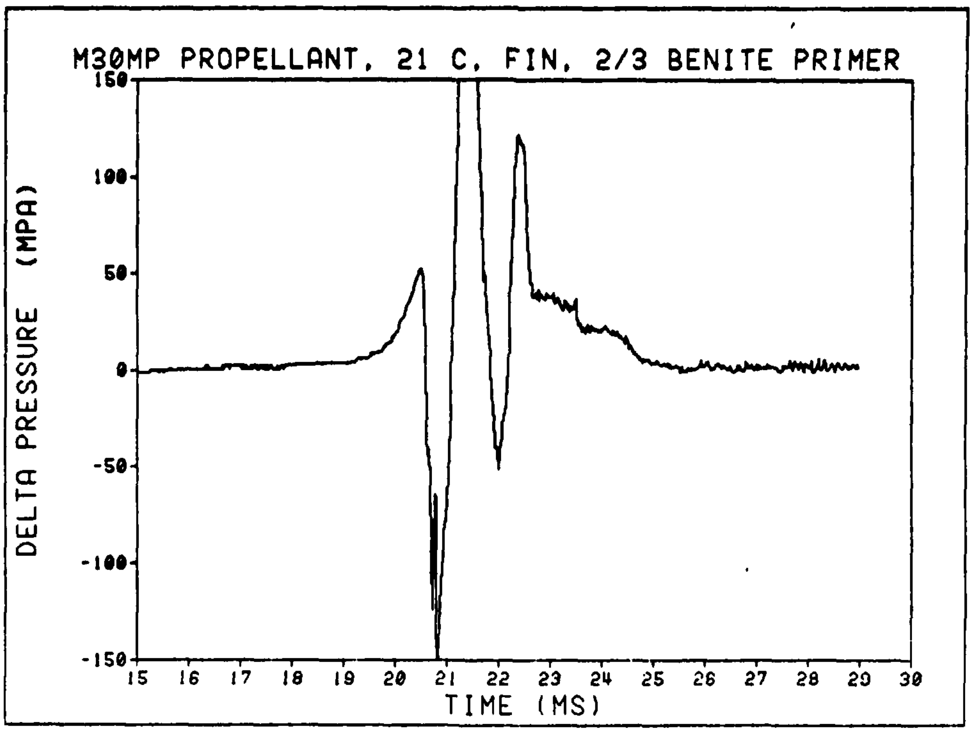
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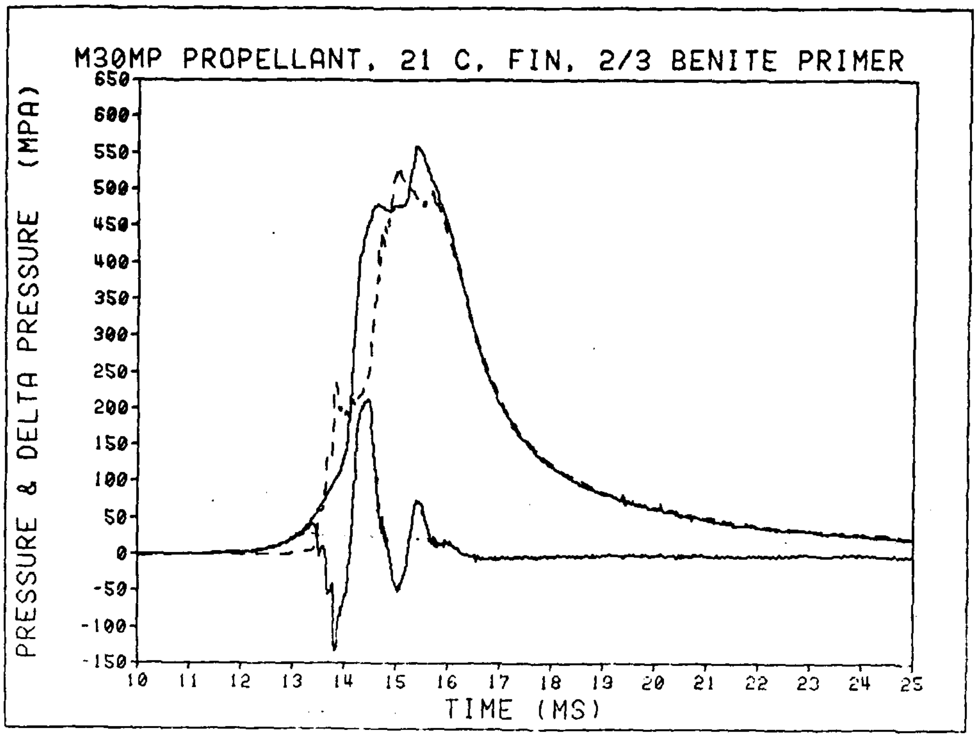
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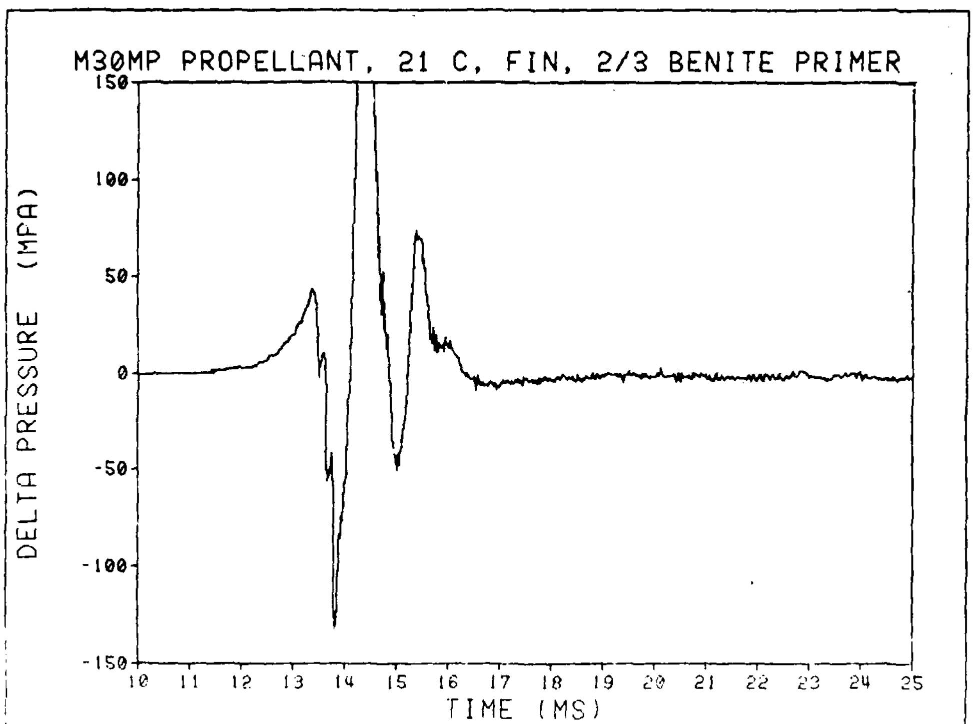
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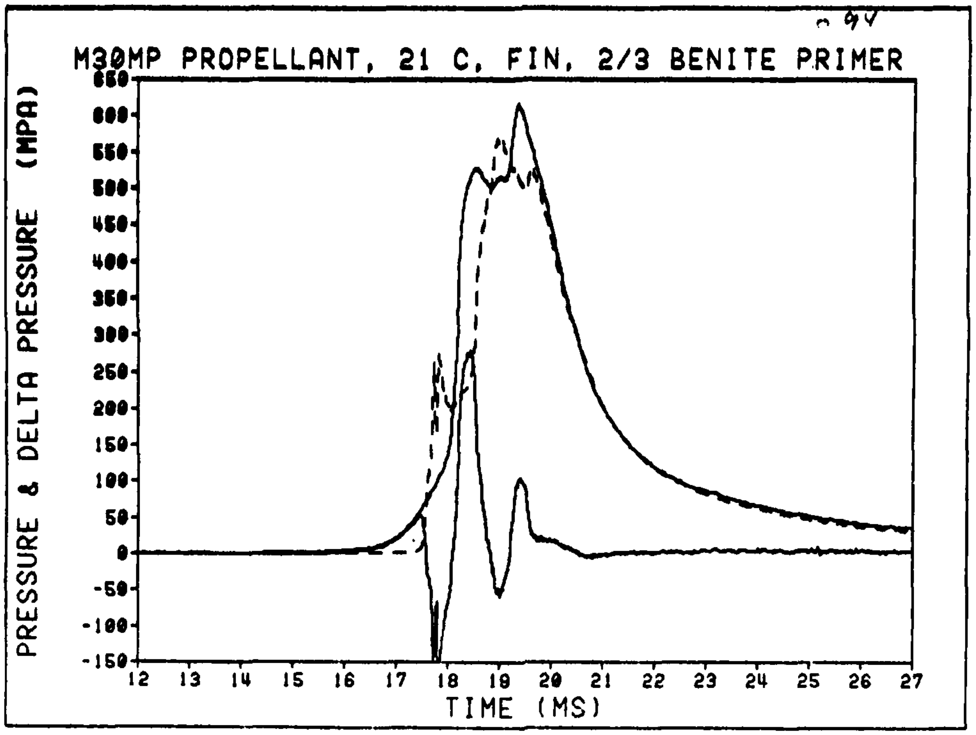
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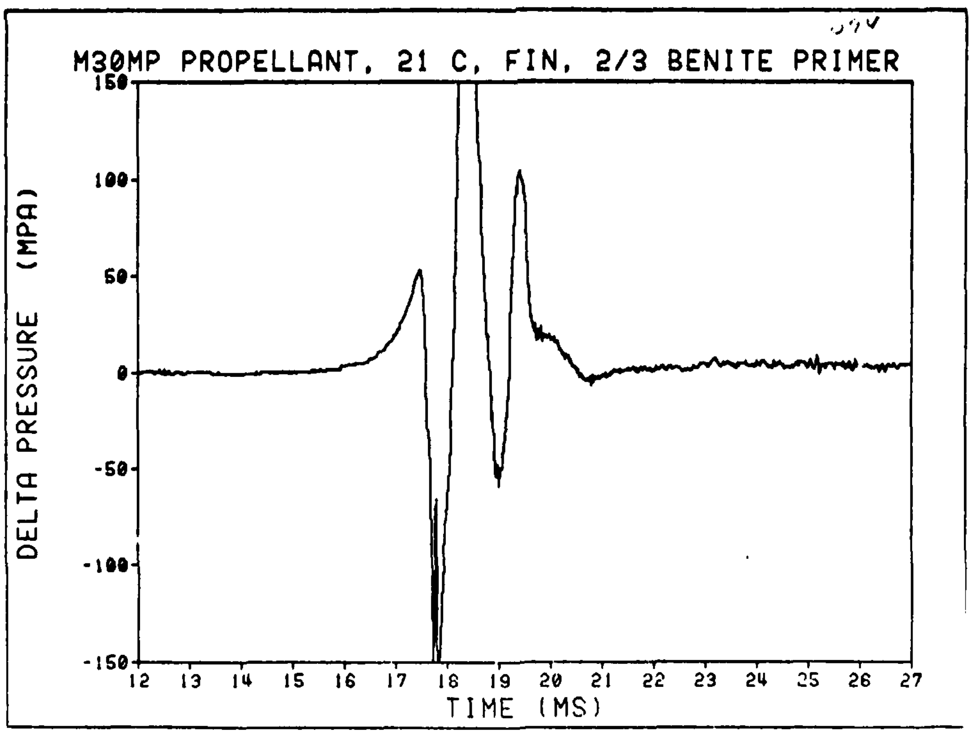
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